Year 1 Progress Report

South Fork Nooksack Chinook

Incubation Evaluation, 2006

by

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Abstract

Twenty artificial redds were constructed in the South Fork Nooksack in 2006 to evaluate over-winter survival for early-timed chinook. Redds were located at 18 sites throughout the mainstem at locations where chinook redds were observed between 2001-2005. Sampling tubes were inserted into the egg pocket area of each artificial redd for extracting hyporheic water during the predicted egg incubation period. Water from each redds was monitored bi-weekly for dissolved oxygen (DO), temperature, and conductivity.

A very high flow event (6th highest on record) on November 6th and sustained flows afterwards, prevented hyporheic water monitoring during the critical last third of the incubation period. Prior to this however, most samples showed adequate DO levels, exceeding 9.0 ppm. One site (river mile 19.7) on the second visit had a DO value of 7.5 ppm. This sample also had a conductivity reading of 228.0 uS, indicating the presence of groundwater in the sample.

Gravel samples were collected to evaluate the infiltration of fine sediments into the redd using a technique that uses lines attached to a folded bag and frame to extract a gravel sample upward through the center of the redd. Only 3 of 20 samples were recovered. One sample taken in the middle section of the mainstem where spawning activity is greatest (river mile 17.0), the percent fines < 0.85 mm was 15.4 % indicating fair survival for egg incubation. Another sample collected from the lower mainstem (river mile 3.9) had much higher fine sediment content (25.9%) indicating poor survival. The third sample was found the following spawning season and was not processed due to the long period since incubation. Observed channel changes and our inability to recover infiltration samples at other sites indicate harmful redd scour had occurred at 11 of the 16 sites (68.8%) in our sample.

Excessive sediment deposition and de-watering was indicated as a factor causing mortality at two sites. At the dewatered site, the active channel shifted laterally more that 50m. At the redd site over twenty chinook fry were discovered in water emerging from an area excavated the previous day. Fry were between 38-41mm with the yolk sac entirely absorbed. The body shape appeared emaciated, suggesting it unlikely that horizontal migration through the gravel to the river would be possible.

At the furthest upstream site fry emergance also appeared to be impeded. Here an accumulation of coarse gravel approximately 1.5 m thick was found over the artificial redd site.

To summarize, we demonstrated the use of artificial redds to evaluate hyporheic water quality and fine sediment infiltration. Factors impacting survival were found to be bed scour (68.8%), redd burial due to deposition (12.5%), and excessive fine sediment infiltration (6.3%).

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Introduction

The Lummi Nation is actively engaged in restoration and other efforts to improve the productivity of depressed salmonid stocks in the Nooksack River Watershed. Despite changes in hatchery operations and harvest management practices, the failure of Nooksack River Chinook populations to respond positively continues to significantly impact the Tribal community and its reserved treaty fishing right.

This is year one of a two-year study. The purpose of this work is to investigate specific limiting factors preventing the recovery of the South Fork Chinook stock. Our focus is the critical egg incubation life stage. Our goal is to identify and clarify specific mechanisms responsible for poor survival so that future habitat restoration and protection activities can be designed to provide the greatest positive benefit to this population.

This study focuses on the hypothesis that the egg-to-fry (ETF) survival for South Fork Nooksack Chinook is most influenced by the following three mechanisms: (1) redd scouring during high flow events (Chapman, 1988; Lisle & Lewis, 1992; Crisp, 1993, 1996; Guerrin & Dumas, 2001a, b) and (2) suffocation of eggs as a result of the infiltration of gravel interstices by fine sediments (DeVries, 2000, McNeil, 1962, Chapman, 1988) and (3) excessive coarse sediment deposition and channel migration preventing fry from reaching the active channel (Chapman, 1988).

Other possible mechanisms that lead to poor ETF survival not investigated here include entombment of fry by surface layer cementing (Beschta and Jackson 1979; Crisp 1993), and reduced female fecundity due to the effects of excessive water temperatures during the pre-spawn holding period.

In investigating redd scour, DeVries, 2000 suggested that mortality from scour occurs in two ways: from eggs being washed out when the bed elevation lowers to their level, and/or by being crushed mechanically by the moving bedload (Crisp 1989). While this second possibility is not directly investigated, significant compaction of the streambed is seen as decrease bed permeability.

Chapman, 1988 in his critical review of studies evaluating effects of fines in redds, found that survival relates positively to DO, gravel permeability and gravel size, and negatively to proportions of fine particles. Measuring interstitial oxygen levels within the redd was a key parameter of importance in evaluating ETF survival. Responding to studies that evaluated circulation within the redd, Chapman noted "incubating embryos require oxygen, not water velocity". This is a reminder that even if acceptable DO values are found in the egg pocket water, it is more important for oxygen to reach the inside the egg. Greig et al. (2005) reported by Levasseur et al.(2006b) "found that clay-sized sediment created a thin, low permeable seal around the eggs which restricted the availability of oxygen to the embryo. They also found that these clay-sized particles could physically block the micropore canals of the egg membrane, thereby restricting oxygen uptake. "

It is believed that peak streamflow events play a critical role in altering conditions that reduce egg-to-fry survival. Besides losses from physical scour of the eggs, Malcolm (2004 & 2003) and others have shown that sustained high flow events cause fine particles to be driven deeper into the sediments, eventually reaching the egg pocket zone of the redd. This results in reducing hydraulic conductivity (circulation of water) in the redd, lowering DO levels in the egg pockets, and possibly coating eggs with clay particles that further prevent oxygen from reaching the inside of the embryo.

In an attempt to evaluate ETF survival, earlier studies in this watershed collected sediment samples near spawning areas and related the percent fines in these samples to egg survival (Schuett-Hames, 1988a & 1988c; Neff, 1992; Hyatt, 2003). Chapman (1988) noted the large body of literature on the intra-gravel ecology of incubating embryos investigates only conditions in the streambed near redds, not within the actual egg pocket area of the redd itself.

As the female excavates the redd, the gravel is made more permeability. A significant shortcoming of these earlier studies was to rely on samples taken from undisturbed streambeds. Chapman concluded that this approach doesn't accurately modeled conditions in a redd, because the substrate was not excavated and backfilled as it would have been by a female in an actual redd. Our approach collects sediment samples from artificial redds which simulate conditions that are created by the female at the start of the egg incubation period.

To monitor DO levels within the redd, we inserted a tube into the artificial redd to the depth of an egg pocket and periodically extracted water samples that were measured for DO, temperature and conductivity. To evaluate sedimentation in the egg pockets we installed a folded bag and frame into the center of the redd. The bag was used to removed a gravel sample from the redd after the incubation period in a technique developed by Levasseur (et. al, 2006). This approach, also provided information on the evidence of egg scour when the sediment bag and frame devices could not be found in redd at the end of the incubation period.

Chinook salmon prefer to spawn in the mainstem portions of watersheds. Geist & Dauble (1998) noted that for Columbia River Chinook, these redds are aggregated in definite clusters associated with complex channel patterns which promote interstitial flow pathways. This clustering of chinook redds has also been observed in the South Fork Nooksack watershed. To investigate whether redds were associated with features noted in the Columbia River study, we mapped chinook redds and large-scale habitat features at each artificial redd site. Changes in the channel during the intragravel development period at each site was also evaluated by comparing lateral movement of features before and following several very high-water events that occurred in the winter of 2006/2007.

METHODS

Study Sites

Sites chosen for constructing artificial redds was based on historic distributions of chinook redds recorded from 2001 to 2005. Efforts were made to locate artificial redds throughout the present range in the mainstem South Fork, giving consideration to access routes to facilitate monitoring during the incubation period. The map in Figure 1 shows the location of artificial redds in the South and Middle Forks of the Nooksack River.

Artificial Redd Construction

In September 2006, we constructed twenty artificial redds in the South Fork and one in the Middle Fork of the Nooksack River. An infiltration cube / bag was inserted in each redd of the type described by Levasseur *et al.* (2006b). At each site we also installed a hyporheic sampling tube similar to the one reported by Malcolm *et. al.* (2004)

Excavation of each redd was done by hand using a small shovel. A pit was dug to approximately 30-35 cm below the bed elevation. A folded sediment collection bag made of sturdy 18 oz. VB "banner" vinyl was placed below the cube frame in the pit. Four ¼" braided nylon recovery lines, 1.5 m long, attached to each corner of the bag were carefully positioned to protrude from the surface after gravel was backfilled into the redd from material upstream in a manner similar to an adult salmon. A measurement was taken using a tape of the top of the infiltration cube frame to the surface of the undisturbed streambed using a pole placed crosswise to the pit.

While material was being backfilled into the sampling cube, the hyporheic sampling tube was placed next to the cube at a depth of approximately 20 cm below the streambed. The tube was made of ¼" ID poly tubing approximately 1m long. The bottom of the open tube was anchored with a PVC end cap. The tube extended from the streambed and was plugged at the end with a small stick. Figures 2 and 3 show a depiction of the artificial redd, the infiltration cube and the hyporheic sampling tube.

Measurements were then made of the length and width of the excavated area and the water depth of the undisturbed bed surrounding the redd. The substrate of the redd was described from measurements of dominant and subdominant particles selected from the back-filled material of the redd. Closest holding habitat was described by estimating the distance from the redd (up or downstream) and describing the type of holding cover present. As the spawning season progressed locations of nearby chinook redds were located by GPS and also measured using method described for artificial redds.

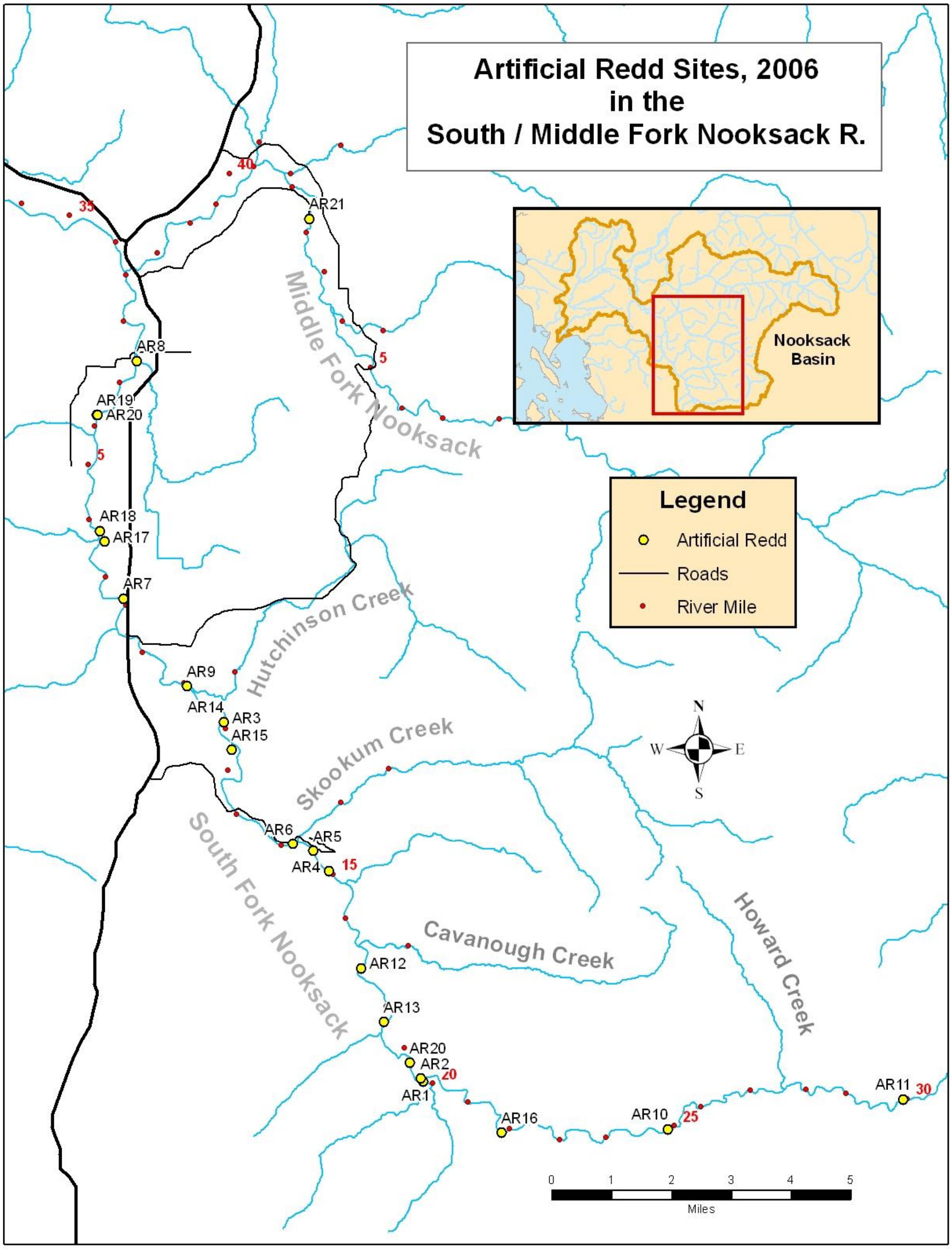


Figure 1. Map showing locations of artificial redds in the Nooksack River South and Middle forks in 2006.

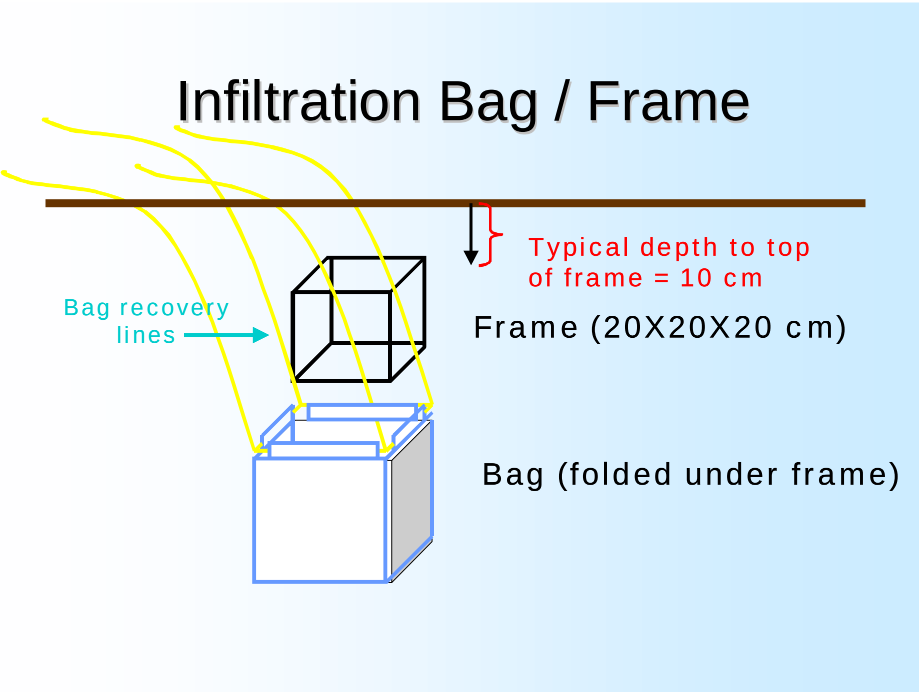


Figure 2. Depiction of infiltration bag and frame.

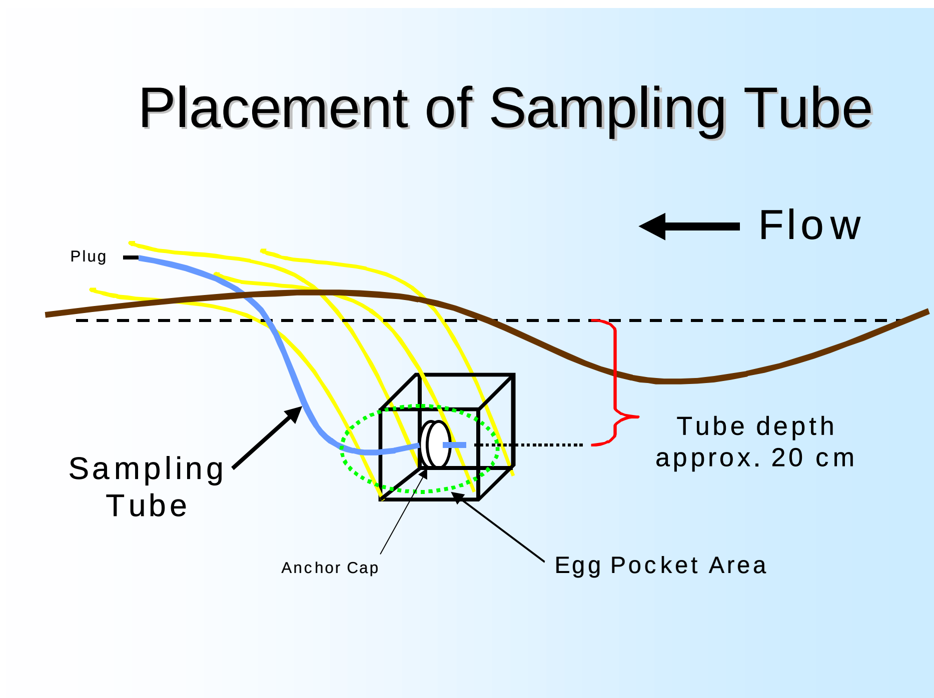


Figure 3. Cross-section of an artificial redd showing placement of hyporheic sampling tube and infiltration cube.

After completion of each artificial redd, its position was determined using a sub-meter Trimble GPS unit. The infiltration cube was constructed of ¼" stainless rod that allowed later detection using a metal detector. The location of each redd was also marked by measuring from two survey stakes placed up and downstream on the nearest stream bank. Survey stakes were of 3/8" steel rebar so they could also be found later with the metal detector. We used a Whites PRL-1 metal detector unit.

Two of the infiltration cubes used were 30X30X20(H)cm, the standard size reported in the Levasseur study. We modified this to a smaller cube 20X20X 20cm for the other nineteen redds used in this study. Figure 4. shows the 20X20X20 cube, sediment sample, and sample bag following retrieval from the substrate.

Figure 4. Infiltration sediment sample after extraction from the substrate. Note the 20X20X20 cm stainless steel frame, sample bag pulled up around the frame, and the attached four lines used to remove the sample from the artificial redd.

Artificial Redd Monitoring

We returned to each site approximately one week following redd construction to sample the surface and groundwater using the hyporheic sampling tubes. Parameters measured included water temperature, conductivity and dissolved oxygen (DO). DO and temperature were measured with a YSI Model 550 Dissolved Oxygen meter. Conductivity was measured with a YSI Model 30-10 Salinity/Conductivity/Temperature meter.

Upon arrival at each site the surface water above the redd was measured for the three parameters and the time was recorded. The hyporheic sampling tube was then attached to a hand pump and a 250 ml water sample was drawn from the tube into a container. Care was taken to clear the tube of any bubbles and to avoid introducing air into the sample that might affect DO measurements. Figure 5 shows a hyporheic water sample being taken from the artificial redd.

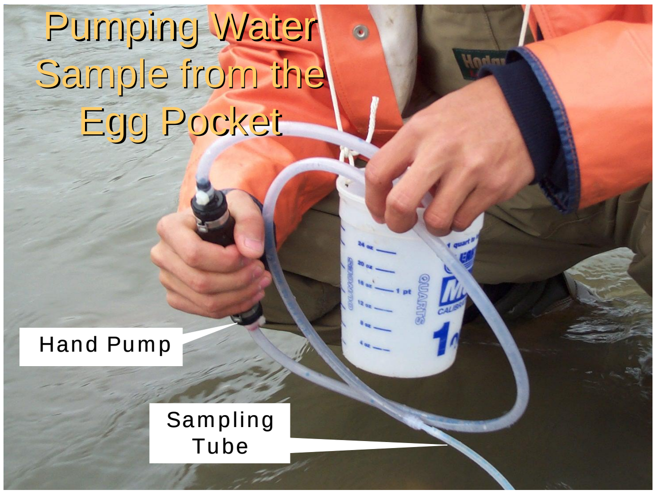


Figure 5. Photo showing use of a hand pump to draw a water sample from the hyporheic sampling tube.

Chinook Redd Characterization

Chinook redds within approximately 30 meters of each artificial redd were mapped and examined. We measured total redd length (including excavation pit), average width, and average depth from four measurements adjacent to the redd. We also measured water velocity over the redd by recording the time for a floating chip to pass the length of the redd. We recorded the substrate characteristics by measuring the b-axis (intermediate axis) distance of dominant and sub-dominate particles and the percent area covered by the dominant particle (Schuett-Hames, et. al., 1999). The nearest holding pool habitat was described and the distance to this feature was measured from the chinook redd. Average redd length, width, depth, and water velocity were calculated. Average dominant and sub-dominant particle size was also determined.

Habitat Mapping in Proximity to Artificial Redds

At the time of redd construction a sub-meter GPS was used to map the habitat approximately 10 meters above and below each redd site. Habitats features measured included the wetted perimeters of both banks, the thalweg, and accumulations of large woody debris (LWD) used as cover structure for holding adult chinook. At some locations we also estimated areas of suitable spawning habitat using historic knowledge of spawning at each site including appropriate substrate size, water depth and velocity.

After the incubation period, these measurements were repeated at each site. Photos were also taken during redd construction and following the incubation period in January and February.

Infiltration Cube / Bag Recovery

Following the incubation period, when streamflows subsided to below approximately 400 cfs, recovery of the infiltration bags became feasible. Clear water conditions with secchi depths of 50 cm or greater facilitated efforts to locate the sediment bag lines and water sampling tubes.

Attempts were made to first locate flagging marking the two survey stakes. If not found, the metal detector was sometimes successful in locating pins that had been buried by accumulated sediment. If one or both pins were found, a tape was used to measure the distance to the spot of the artificial redd. A stick was inserted into the bed at this spot.

Where pins could not be found or where only one was located, the sub-meter GPS was used to navigate to the site. In open areas with more that 9 satellites were able to locate the artificial redd sites to within approximately 0.5 m.

When the site was found, the metal detector was then used to locate the stainless steel frame of the infiltration cube. Often stones containing iron compounds would set off the metal detector and so these would be removed and the area probed again until a signal marking the cube frame was found. Prior to excavating the infiltration bag, water depth and velocity measurements were taken above the redd site.

At sites of suitable depths (less than 0.5 m) we were able to excavate a 1m square area at the site to a depth of approximately 40 cm below the bed elevation. The metal detector was used during this process to more precisely locate the exact spot to be excavated. When a frame was detected, a strong audible tone was heard over the area above the cube. This metal detector was capable of locating a frame through a sediment layer at least 30cm thick.

During the excavation as the four recovery lines were found, care would be taken not to excavate below the top of the frame to the extent possible to find the lines. The lines were then gently lifted upwards while initially holding the cube frame down. During the bag extraction the opening surrounded the cube. The bag /cube / sediment sample was raised clear of the water and transferred to a 3 gallon plastic pail to air dry prior to processing.

We recorded the maximum depth of excavation and the distance from the top of the frame to the surface of the bed.

Sediment Sample Processing

Samples removed from artificial redds were processed using the volumetric (wet method as described by Schuett-Hames, et. al., 1999. This method was originally used by McNeil and Ahnell, 1960 and later with refinements by Koski, 1966 and 1975; Cederholm and Lestelle, 1974; Tagart, 1976. This technique was also used in earlier studies in the Nooksack, from samples collected with the McNeil Sampler (Schuett-Hames, 1984; Hyatt & Rabang, 2003). Figure 20 shows the sample processing station which includes the stack of 10 sieves, the catch basin, and graduated cylinder attached to the basin to collect and measure the clay and silt size classes less than 0.125 mm.

Figure 6. Photo of sediment processing station showing the stack of sieves, sieve stand, catch basin and graduated cylinder for collecting fines.

RESULTS

Redd Construction

Table 1 below lists the twenty one artificial redds that were constructed from September 7th to October 2nd, 2006. The ID number refers to the consecutive order of construction. All redds were located in the South Fork of the Nooksack except AR21 which was in the Middle Fork. Water depths ranged from 16 – 38.7 cm with average of 26.8 cm, while water velocities ranged from 0.38 - 0.86 m/s with an average of 0.53 m/s. Eventually chinook redds appeared within 25m of all sites except the upper most South Fork site (AR11).

Table 1. List of artificial redds constructed in the South and Middle Forks of the Nooksack River in 2006.

Artificial Redds Constructed in 2006

Redd ID #	Location	Date Const.	River Mile	Bank	Infiltration Cube/Bag Size	Gravel Sample	Water Depth (cm)	Water Velocity (m/s)	Chinook Redds w/in 25 m
AR8	Above Potter Br.	10/2/06	2.03	R	Small	No	23	0.6	2
AR19	Below Sygitowitz Cr.	9/28/06	3.87	L	Small	No	25	0.86	1
AR18	Above Standard Cr., dwnstr.	9/28/06	6.2	M	Small	No	38.7	0.63	5
AR17	Above Standard Cr., upnstr.	9/28/06	6.36	L	Small	No	29.5	0.38	5
AR7	Above RR Bridge	9/15/06	7.83	L	Small	No	37	0.71	3
AR9	Below Hutchinson Cr.	9/18/06	10.05	R	Small	No	32.2	0.5	3
AR3	Above Hutchinson Cr.	9/12/06	10.89	R	Large	No	26	N/A	3
AR14	Above Hutchinson Cr.	9/12/06	10.89	R	Small	Yes	29.8	0.53	3
AR15	Below Saxon Creek	9/25/06	11.48	M	Small	No	26.5	0.8	2
AR6	Below Skookum Creek	9/13/06	14.17	L	Small	No	16	0.56	3
AR5	Skookum Hole	9/13/06	14.52	M	Small	No	28	0.28	1
AR4	Above Stream Gage	9/13/06	14.92	R	Small	No	30	0.57	1
AR12	Ford River Crossing	9/22/06	17.01	L	Small	No	29.8	0.6	7
AR13	Above RM 18 Bridge	9/22/06	18.31	R	Small	No	36.5	0.6	4
AR20	Above Eagle Nest	10/6/06	19.33	L	Small	Yes	25.8	0.43	4
AR1	Below Plumbago Cr., LB	9/7/06	19.78	L	Large	No	8	0.38	1
AR2	Below Plumbago Cr., RB	9/7/06	19.73	R	Large	No	25	0.51	4
AR16	Above Larson's Bridge	9/26/06	21.86	R	Small	No	22.3	0.51	2
AR10	Above 200 Road Bridge	9/19/06	24.9	L	Small	No	32	0.55	1
AR11	Above 330 Road Bridge	9/19/06	29.94	L	Small	No	26	0.6	0
AR21	M. Fork, Rutzatz Rd.	9/29/06	1.8	L	Small	No	16	0.58	3

The photo in Figure 7 shows a completed artificial redd. The hyporheic sampling tube and the infiltration cube recovery lines can be seen protruding from the substrate.

Figure 7. Photo of artificial redd # AR-6 showing exposed hyporheic sampling tube and infiltration cube retrieval lines.

The distribution of artificial redds relative to early-timed chinook redds (redds found prior to 10/1) located in 2006 can be seen in Figure 7. The timing of redd construction relative to observations of chinook redds is shown in Figure 8. Dates of artificial redd construction and locations throughout the mainstem South Fork Nooksack generally represent the timing and distributions of early-timed chinook redds observed in the field in 2006.

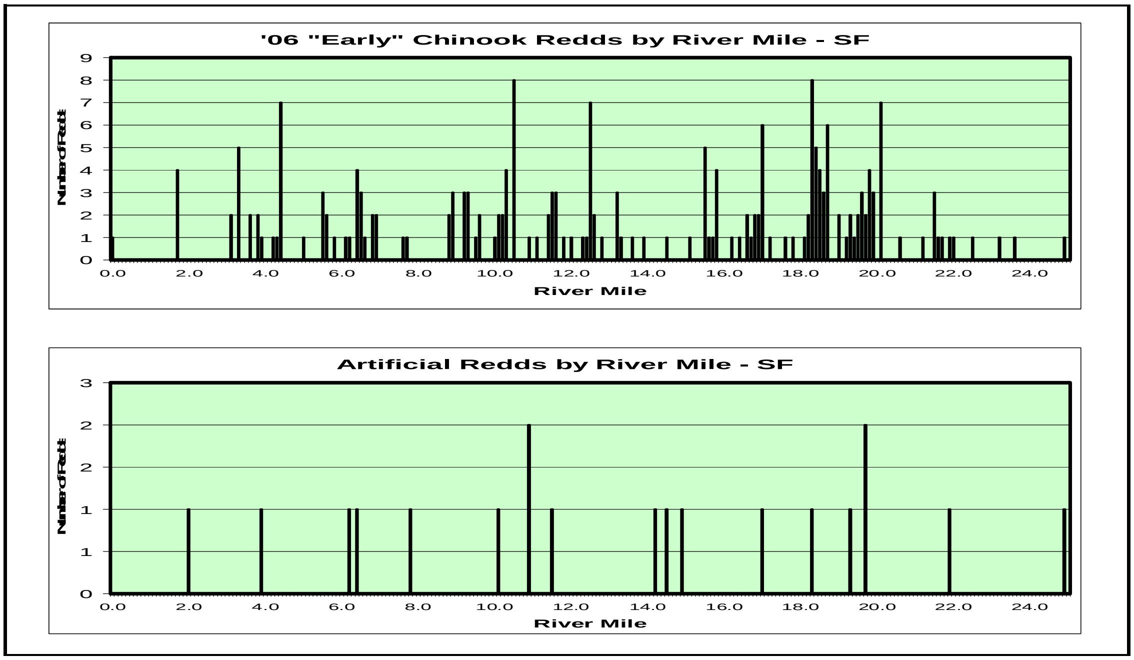


Figure 8. Plots of early-timed chinook redds by river mile on the South Fork Nooksack relative to locations of artificial redds constructed in 2006.

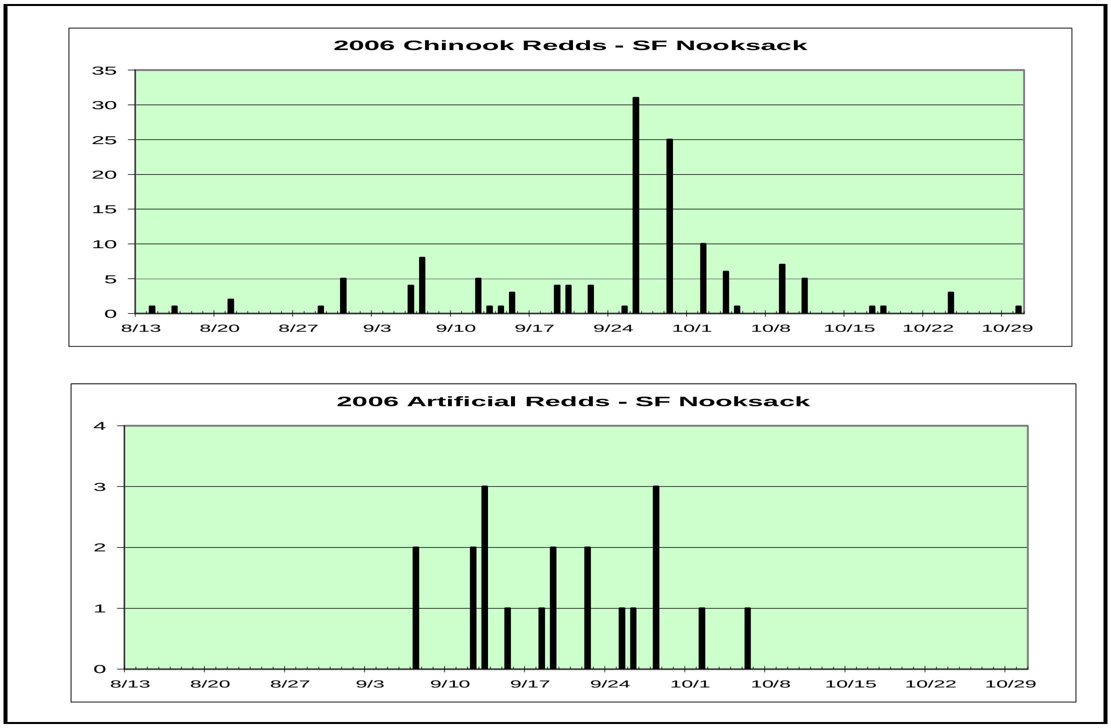


Figure 9. Plots showing dates of chinook redd observations relative to dates when artificial redds were constructed in 2006.

Redd Monitoring

Ambient water from the river at each site and water drawn from the artificial redd egg pockets was measured for temperature, conductivity and dissolved oxygen (DO). Regular bi-weekly redd monitoring began on 10/2 and continued until 10/31 when river flows increased to levels that prevented further sampling. A span of approximately one week elapsed after redd construction before each redd was monitored.

All 20 redds in the South Fork were monitored. Most sites were sampled two times or more. Monitoring took place at approximately two weeks intervals. Monitoring results were grouped into two sampling periods, 10/2 –11 and 10/23-31. Two redds, AR19 and AR15 could not be located during the second sampling period. The gravel sample retrieving lines were visible for AR19, but the sampling tube was missing (presence of several chinook redds nearby may indicate the tube was dug out by a spawning female). No trace of the sampling tube or the retrieval lines could be found in the swift water where AR 15 was constructed. The single Middle Fork redd was monitored only once during the second monitoring period.

The monitoring period covered the peak hatching period as calculated by a temperature model based on river water temperatures and known rates of chinook embryo development ("Redd Emergence Prediction Tool", Lummi Natural Resources Dept.). The peak hatch period is shown in Figure 10, which is a plot of average daily discharge during the early-chinook egg incubation period from a USGS stream gage at river mile 14.8.

Shown also are dates when artificial redds were constructed and monitored. The large peak flow event on November 6th temporarily disabled the gage, but later maximum stage height calculations estimated instantaneous flows to have approached 16,000 cfs. This was the 6th highest flow recorded in the 30-year history of the record, corresponding to a reoccurrence flow interval of 5-10 years.

Appendix Table B lists the artificial redd monitoring data for each monitoring period. Temperature data for each redd is summarized in plots found in Figure 11A/B. Dissolved oxygen (DO) measurements appear in Figures 12A/B. Conductivity values are shown in Figure 13A/B.

Ambient river water temperatures ranged from a high of 12.6 C below Hutchinson Creek to a low of 3.0 C on the first and last day of monitoring period respectively. River water DO levels ranged from a low of 9.7 ppm on the first day of sampling at the lowest most redd location at river mile (RM) 2.0 to a high of 14.0 ppm on

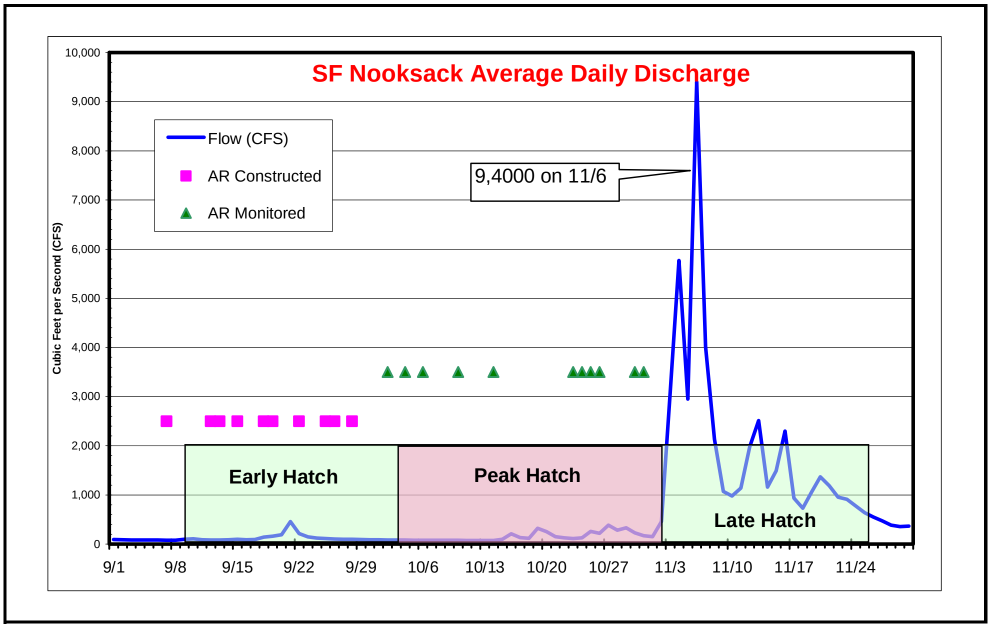
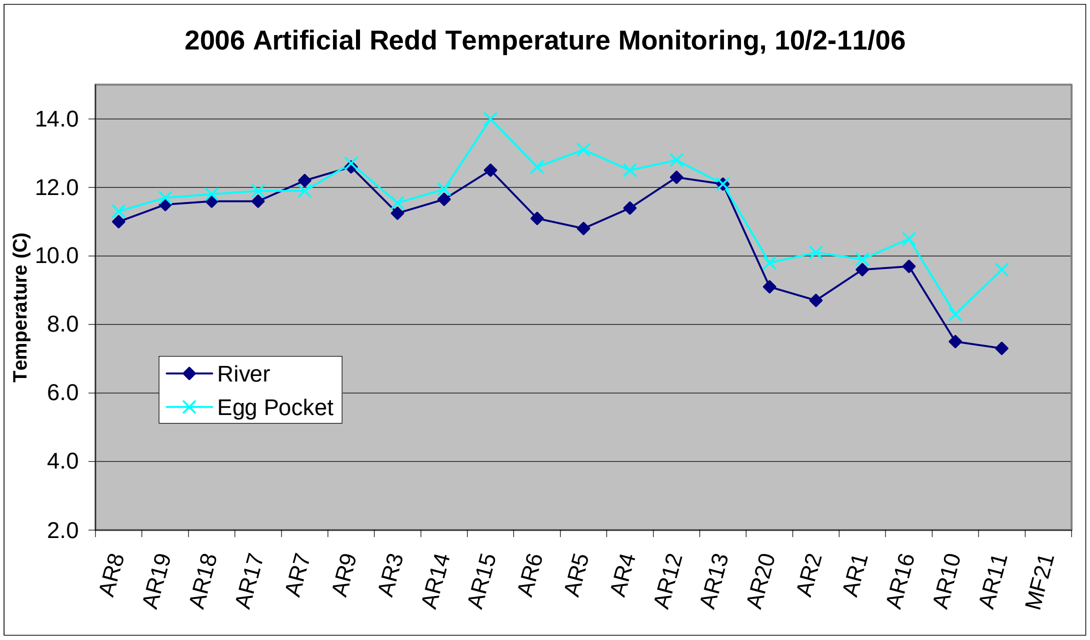


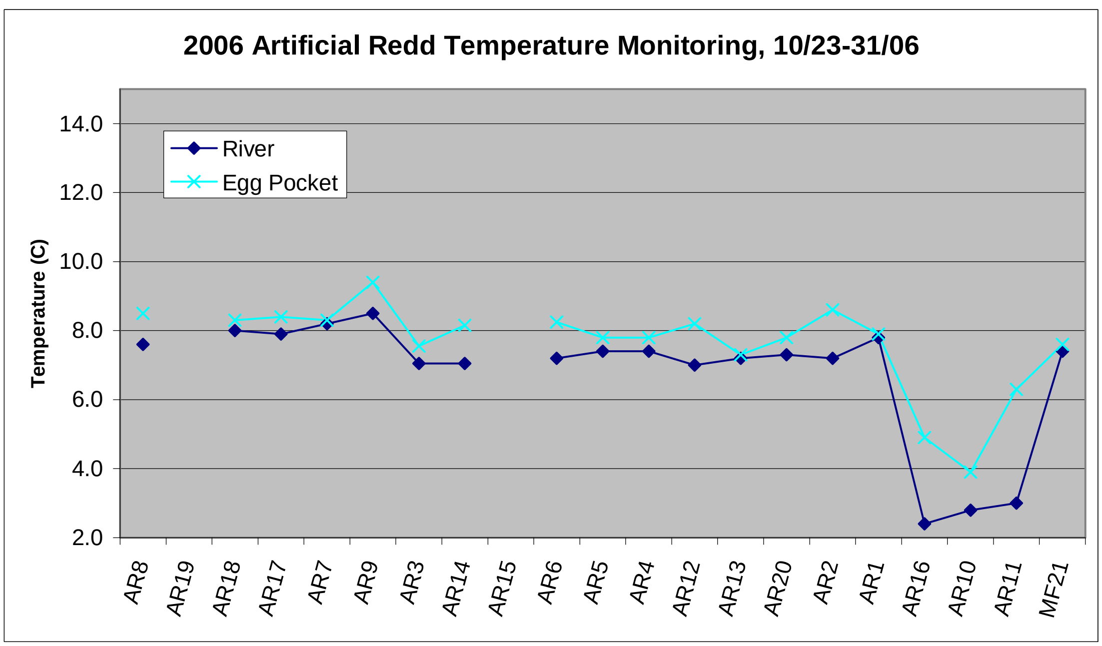
Figure 10. Average daily discharge from a USGS gage on the South Fork Nooksack River during the early-chinook incubation period.

the last day of sampling at a redd location at river mile 21.9. Conductivity values of surface water were variable generally exceeding 100 uS for all measurements.

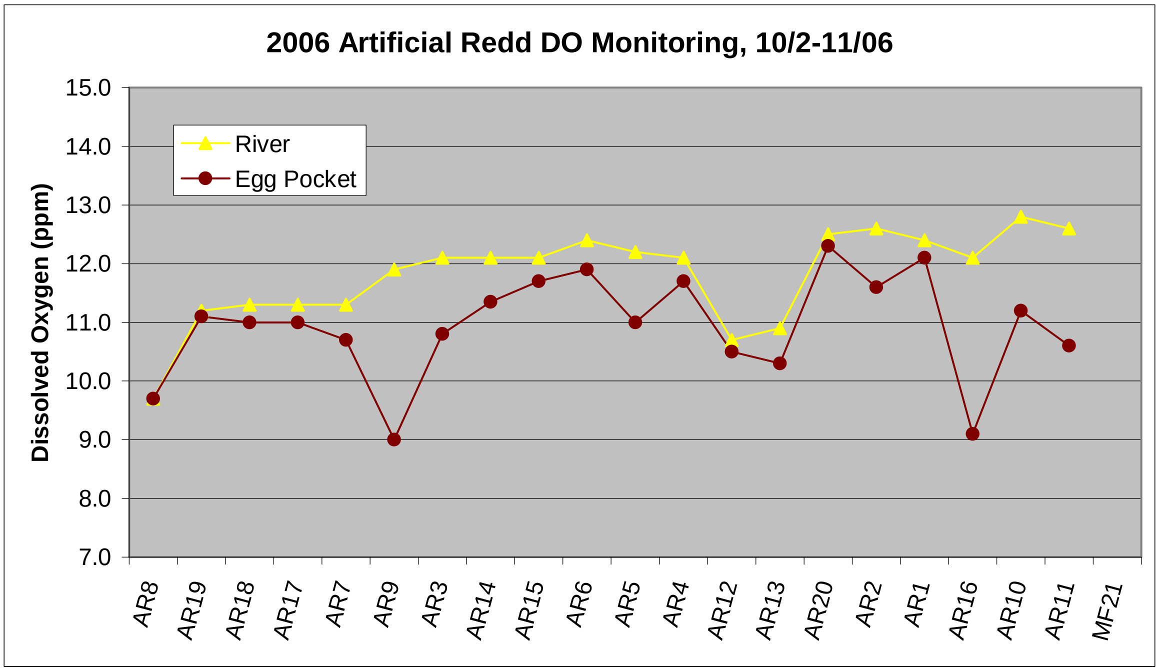
Figure 11A/B show egg pocket temperatures generally followed those of the river water samples. However AR15, AR6, AR5, and AR4 had subsurface temperatures that were approximately 2 C higher than river temperatures. These were all measured on 10/4, a very warm day when a pump failure may have contributed to the warming of the egg pocket water samples.

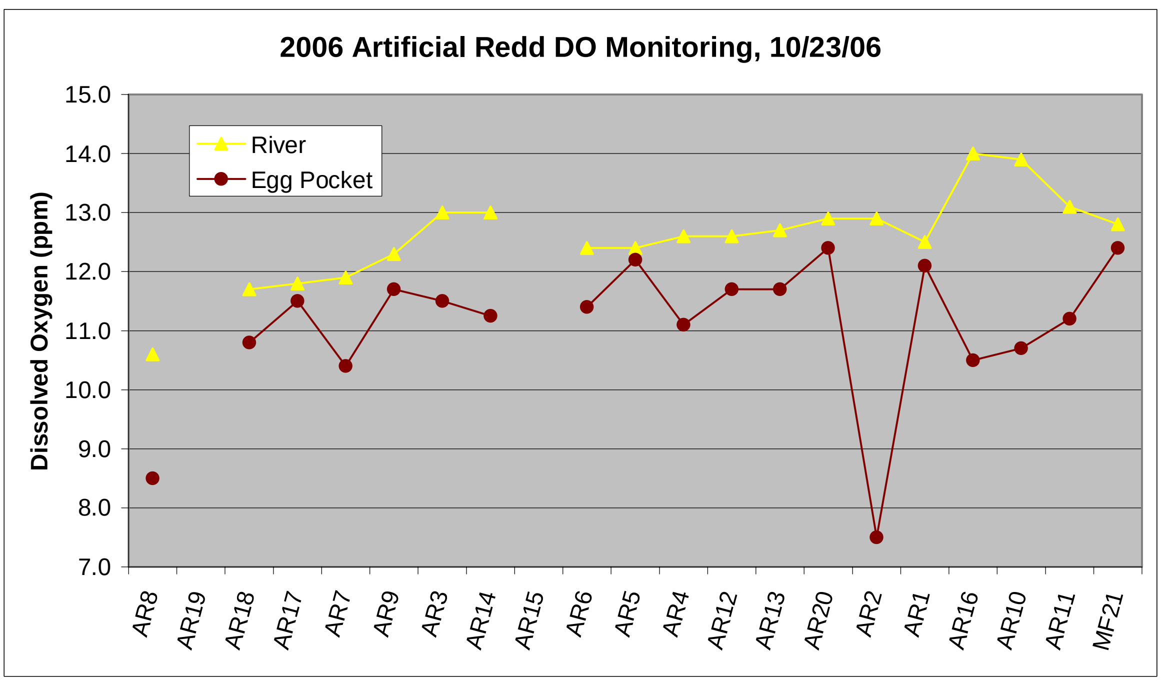
Dissolved oxygen (DO) measurements are plotted for all redds in Figure 11A/B. **All egg pocket DO values, with the exception of two sites, were above 9.0 ppm indicating good survival conditions for incubating eggs. Artificial redd #AR2, had the lowest DO value recorded, 7.5 ppm.** Site AR8 had a DO of 8.5 ppm. Studies coorelating egg survival in the field using artificial reds containing live eggs where DO from egg pocket water was monitored (Malcolm et al, 2003) report: "Where mean DO concentrations were less than 7.6 mg l^{-1} embryo survival to hatch was negligible, but mortality rates were near-zero at mean DO concentrations of about 11.7 l^{-1}. This one low DO reading for AR2 taken near the peak of the hatching period 10/24/06 suggests the potential for poor survival from low DO values may exist in some locations during the later stages of the egg incubation period for South Fork Chinook.



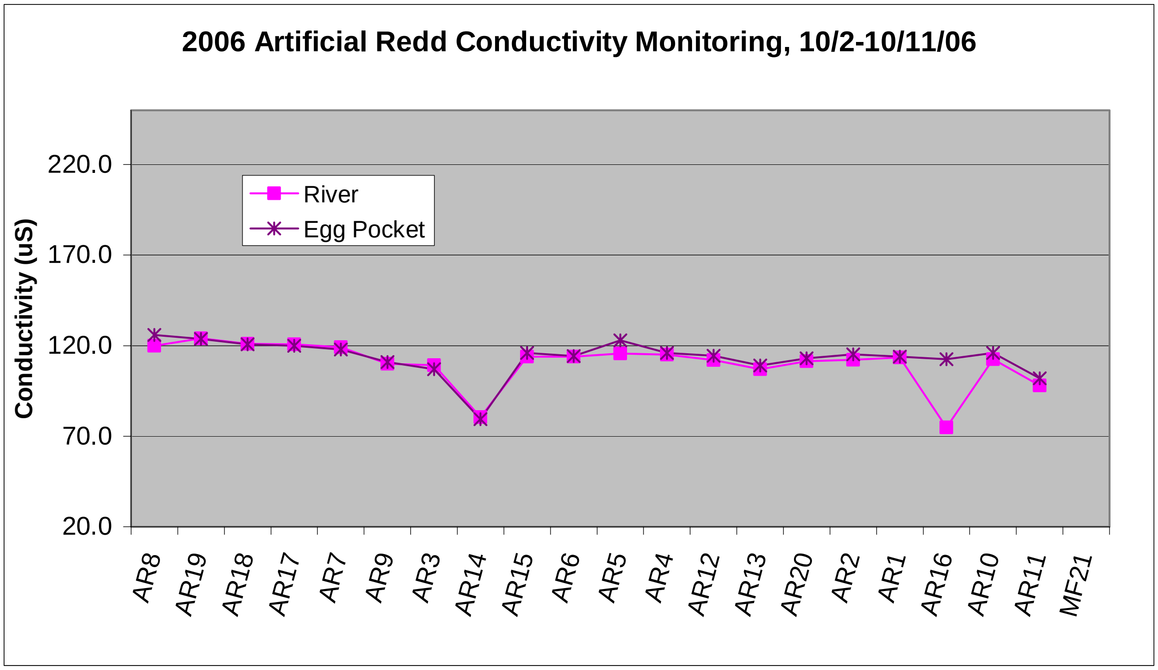


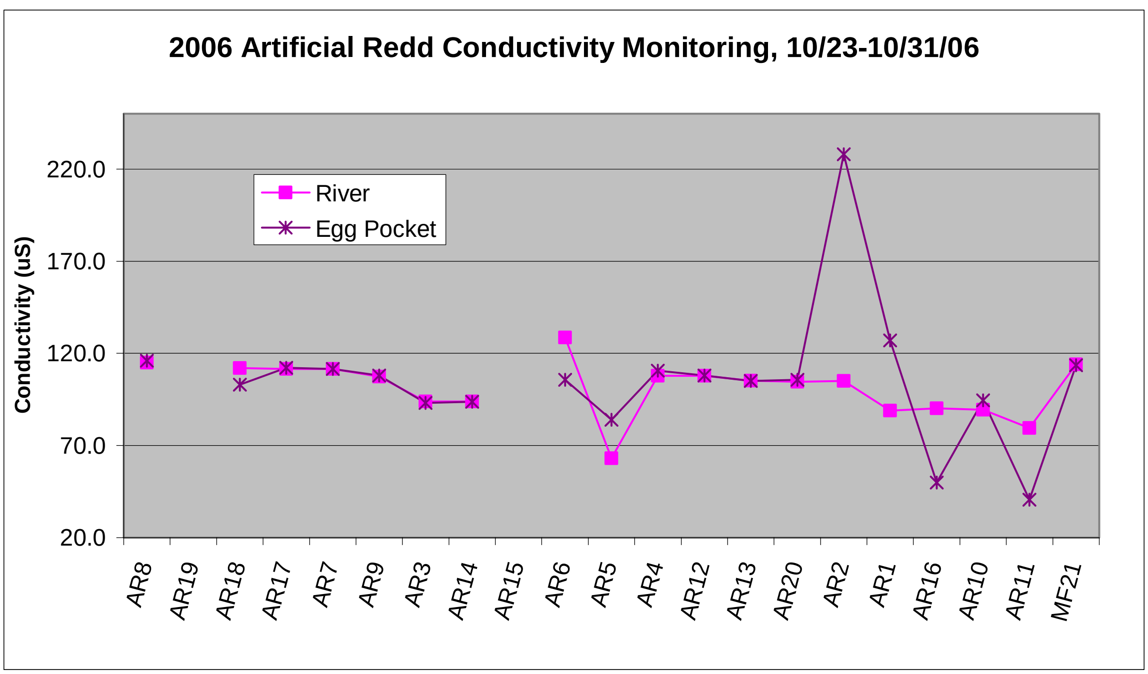
Figures 11A & 11B. Plots of river and egg pocket water temperatures from artificial redds for the periods 10/2 – 10/11/06 and 10/23 – 10/31/06. Redds are listed left to right from lower-most to upper-most on the South Fork Nooksack River. Redd MF21 is located on the Middle Fork.





Figures 12A & 12B. Plots of river and egg pocket dissolved oxygen from water sampled from artificial redds for the period 10/2 – 10/11/06 and 10/23 –10/31/06.





Figures 13A & 13B. Plots of river and egg pocket conductivity from artificial redds for the period 10/2 – 10/11/06 and 10/23 –10/31/06.

Figures 13A and 13B are plots of water conductivitiy. For all but one site (AR2, discussed above), conductivities are well below 150 uS, indicating no significant growndwater influence at the time we sampled. Geist & Dauble, 1998 found river water measurements to be between 125-150 uS in the Columbia River, while groundwater sources were typically between 300-500 uS. At site AR2 the conductivity was 228.0 uS, indicating presence of groundwater within the egg pocket area of the redd. **The presence of groundwater, which typically has low oxygen levels, could explain, in part, the cause for the low DO reading taken at AR2.**

Artificial / Chinook Redd Characterization

Redd dimensions, substrate size, and proximity to holding habitat is summarized for artificial and nearby chinook redds in Appendix A and B respectively. Comparisons of average dimensions for the artificial redds and nearby chinook redds were respectively: length = 2.7 / 5.5 m; width = 1.3 / 2.5 m; depth = 26.8 / 27.9 cm; velocity = 0.7 / 0.8 m/s. The substrate surrounding the redds had a dominant particle size measuring 9.5 / 9.4 cm and sub-dominant particle measuring 5.5 / 5.1 cm . The average distance to pool habitat measured 34.3 / 38.8 m for artificial and chinook redds respectively. While the artificial redd was smaller in length and width, its depth, water velocity, substrate size, and distance to holding habitat was similar to those chinook redds measured.

Habitat Mapping

Appendix D1 thru D18 are site maps prepared using ARCmap showing habitat features mapped during redd construction and again after peak flow events. Also shown are locations of artificial redds and nearby chinook redds. Features mapped include wetted perimeters, thalwegs, sand/gravel bars, holding pools, and associated large woody debris (LWD).

Many years of mapping chinook redds in the South Fork show that they are often aggregated in clusters. Geist & Dauble (1998) found that in the Columbia River Fall Chinook redd clusters were associated with channel features indicating areas of streambed upwelling and downwelling. One objective of this work was to see if redd clusters in the South Fork are associated with similar features that might indicate the presence of hyporheic flow pathways. Examples of these features are shown in Figure 14. and include tributary alluvial areas, gravel islands, point bars, and lateral bars.

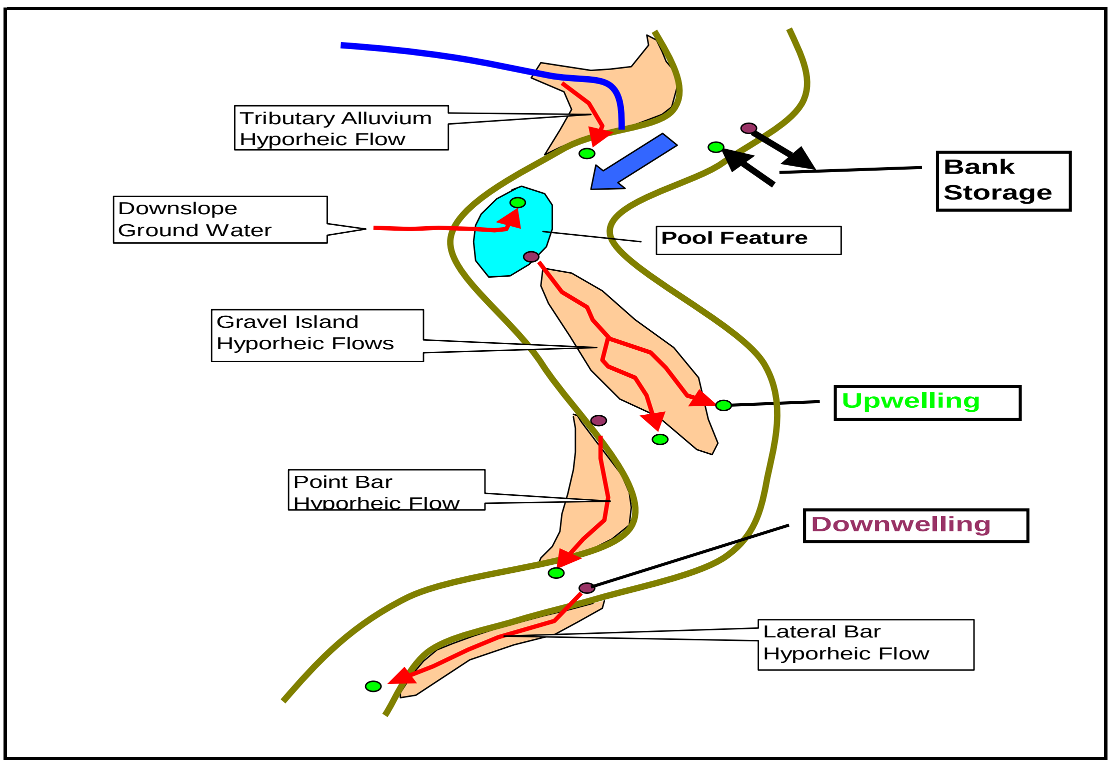


Figure 14. Conceptual model of hyporheic flow pathways within an alluvial river reach (modified from Geist & Dauble, 1998). Flow pathways are more accurately described as a complex braided network of interconnected corridors with many upwelling and downwelling sites.

For chinook redds near artificial redd sites in 2006, Table 2 summarizes the occurrence of these hyporheic flow indicator features. Of 52 chinook redds mapped, **over half (51.9%) were associated with point bars (27 of 52 redds) and most of these (19 of 27) were near the downstream edge of the sandbar, indicating possible upwelling areas.** Deep pools were associated with redds in 38.5% of the observations, with most redds (16 of 20) located downstream of the pool feature (pools defined as being at least 1 m deep). Next most important were tributary alluvium areas, which were found in 17 of the 52 redds mapped (32.7%). Lateral bars and gravel island features were next, with 13 and 12 redds in association to these features, respectively. All redds near gravel island observations were located downstream of these features. **Of the feature associations examined, 69 of the 89 associations or 77.5% were downstream of the feature, indicating upwelling areas.**

Table 2. Summary of chinook redd observations in study reaches and association with features indicating hyporheic flow pathways, 9/7/06 – 10/2/06.

South Fork Nooksack Chinook Redd Observations
in Proximity to Selected Hyporheic Flow Features[1]
9/7/06 - 10/2/06

Artificial Redd Reach	Chinook Redds Observed	Dwnstr. of Tributary Alluvium	Upstream Area of Deep Pool	Dwnstr. Area of Deep Pool	Upstream Area of Gravel Island	Dwnstr. Area of Gravel Island	Upstream Area of Point Bar	Dwnstr. Area of Point Bar	Upstream Area of Lateral Bar	Dwnstr. Area of Lateral Bar
AR8	2	2							2	
AR19	1	1					1			
AR18	5	5						5		
AR17	5						5			
AR7	3							3		3
AR9	3	3							3	
AR3/14	3		3						3	
AR15	2									2
AR6	3					3				
AR5	1	1	1							
AR4	1									
AR12	7			7				7		
AR13	4			4				4		
AR20	4			4		4				
AR1	1					1				
AR2	4	4				4				
AR16	2						2			
AR10	1	1		1						
AR11	0							0		
N=	**52**	**17**	**4**	**16**	**0**	**12**	**8**	**19**	**8**	**5**
		17	**20**		**12**		**27**		**13**	

[1]feature within 30 meters of redd

The second objective of the habitat mapping work was to document pre- and post- flow event conditions which might provide an indication of relative channel stability at artificial redd sites. Habitat maps in Appendix D provided the comparison for this analysis. Because no elevation data was available to assess channel changes, this evaluation relies on large-scale lateral changes in the location of features mapped during redd construction and again after high flows. We examined the changes in the following features in this analysis: the thalweg, sandbars, sand/gravel islands, streambanks, and pools greater than 1 m deep. While actual flow values differed somewhat on days we conducted the pre- and post-event mapping, the location of the wetted edge from this flow difference would, in most cases be immeasurable, relative to the large-scale channel changes that we observed.

Table 3 summarizes the presence of five indicators used to assess channel instability at each AR site. For each indicator, the criteria used to define channel instability is: pool filling exceeding 1m in depth; sandbar accretion exceeding 10m laterally; sandbar erosion exceeding 10 m; thalweg movement greater than 5m towards the artificial redd site; and stream bank edge erosion exceeding 5 m laterally from pre-event wetted edge. Only changes occurring within 50m our artificial redd sites were assessed. We used an ARCmap measuring tool to determine if the criterion was exceeded for each of these indicators at each AR site.

Table 3. Indicators of channel instability observed in proximity to artificial redds constructed in 2006. Results based on habitat mapping comparisons at each study reach before and after high flow events from 11/6/06 to 1/29/07.

South Fork Nooksack Channel Stability Indicators
in Proximinty to Artificial Redds following Flow Events of 11/5/06

Artificial Redd Reach	Chinook Redds Observed	Artificial Redd Location	Pool Filling	Sandbar Accretion	Sandbar Erosion	Thalweg Movement Towards	Bank Erosion	Total Indicators	Suggested Survival
AR8	2	Above Potter Br.		1				**1**	Fair
AR19	1	Below Sygitowitz Cr.	Unkn	Unkn	Unkn	Unkn	Unkn	Unkn	Unkn
AR18	5	Above Standard Cr., dwnstr.	1	1	1	1	1	**5**	**Poor**
AR17	5	Above Standard Cr., upnstr.					1	**1**	Fair
AR7	3	Above RR Bridge		1	1			**2**	**Poor**
AR9	3	Below Hutchinson Cr.						**0**	Good
AR3/14	3	Above Hutchinson Cr.	1		1	1	1	**4**	**Poor**
AR15	2	Below Saxon Creek		1	1	1		**3**	**Poor**
AR6	3	Below Skookum Creek						**0**	Good
AR5	1	Skookum Hole				1		**1**	Fair
AR4	1	Above Stream Gage					1	**1**	Fair
AR12	7	Ford River Crossing						**0**	Good
AR13	4	Above RM 18 Bridge		1	1		1	**3**	**Poor**
AR20	4	Above Eagle Nest	1	1				**2**	**Poor**
AR1	1	Below Plumbago Cr., LB		1	1			**2**	**Poor**
AR2	4	Below Plumbago Cr., RB		1	1	1		**3**	**Poor**
AR16	2	Above Larson's Bridge	Unkn	Unkn	Unkn	Unkn	Unkn	Unkn	Unkn
AR10	1	Above 200 Road Bridge						**0**	Good
AR11	0	Above 330 Road Bridge		1			1	**2**	**Poor**
	52		**3**	**9**	**7**	**5**	**6**		

Table 3 also offers an estimate of redd survival for each site. If a site had 2 or more channel instability indicators it was assigned a poor survival rating. Those with 1 indicator received a fair rating and those with no indicators were given a good survival rating. The most common indicator present was sandbar accretion (9) followed by sandbar erosion (7) and bank cutting (6), and thalweg movement (5). Pool filling was least common, but when observed, it was impressive. Two sites AR20 and AR11 had accretion to the extent that the sites were de-watered when the second mapping occurred. Table 3 suggests that overall **redd survival was good at 23.5% (4 of 17) of the reaches examined**.

Examples of Channel Instability

A dramatic example of channel instability observed following the high flows of 2006/2007 is shown on the habitat map in Figure 15 (from Appendix D). This is a reach above Standard Creek (river mile 6.2) where artificial redds AR 17 and AR18 were constructed. Following the high flows, we found several hundred meters of the right stream bank between our AR sites had been severely eroded causing a loss of approximately 25 meters of bank material approximately ~3m high. Downstream, the sandbar on the right bank grew approximately 100 m in length, almost completely filling in a pool that was mapped in the fall as chinook holding habitat. This sandbar apparently covered three chinook redds we mapped earlier, but appeared to somewhat miss AR18. Features mapped are wetted margins so without elevation data it is impossible to determine the extent of bed changes that occurred at our redd sites. On the opposite bank, this sandbar also showed a dramatic growth towards the eroding right bank. The location of the sandbar wetted edge, which had not significantly changed in two years when the aerial photo was taken, moved approximately 100 m towards the right bank, completely filling the channel that was mapped the previous fall!

Another illustration of channel instability occurred in the reach above Hutchinson Creek (river mile 10.9) where artificial redds AR3 and AR14 were built. Figure 16 shows a photo taken during redd construction. Following the high flow events, the entire pool shown next to the logjam downstream was completely filled in. Sometime during high flows, the left bank was cut down (removing our survey pins) and a new overflow channel was formed. This moved the logjam shown in the photo 50 meters downstream. These changes are shown on the habitat map in Appendix D2. The entire pool, measuring approximately 70 m long X 10 m wide was completely filled in when we returned to search for the infiltration sediment samples (without success) from AR3 and AR14.

Bank erosion, while not as dramatic as some changes observed, was responsible for the disappearance of many of our survey pins used to locate artificial redds. Figure 17 is a photo of active bank cutting adjacent to artificial redd AR4, just above the USGS stream gage at river mile 14.0. Flagging marking the location of our survey pins can be seen on the submerged fallen tree in the

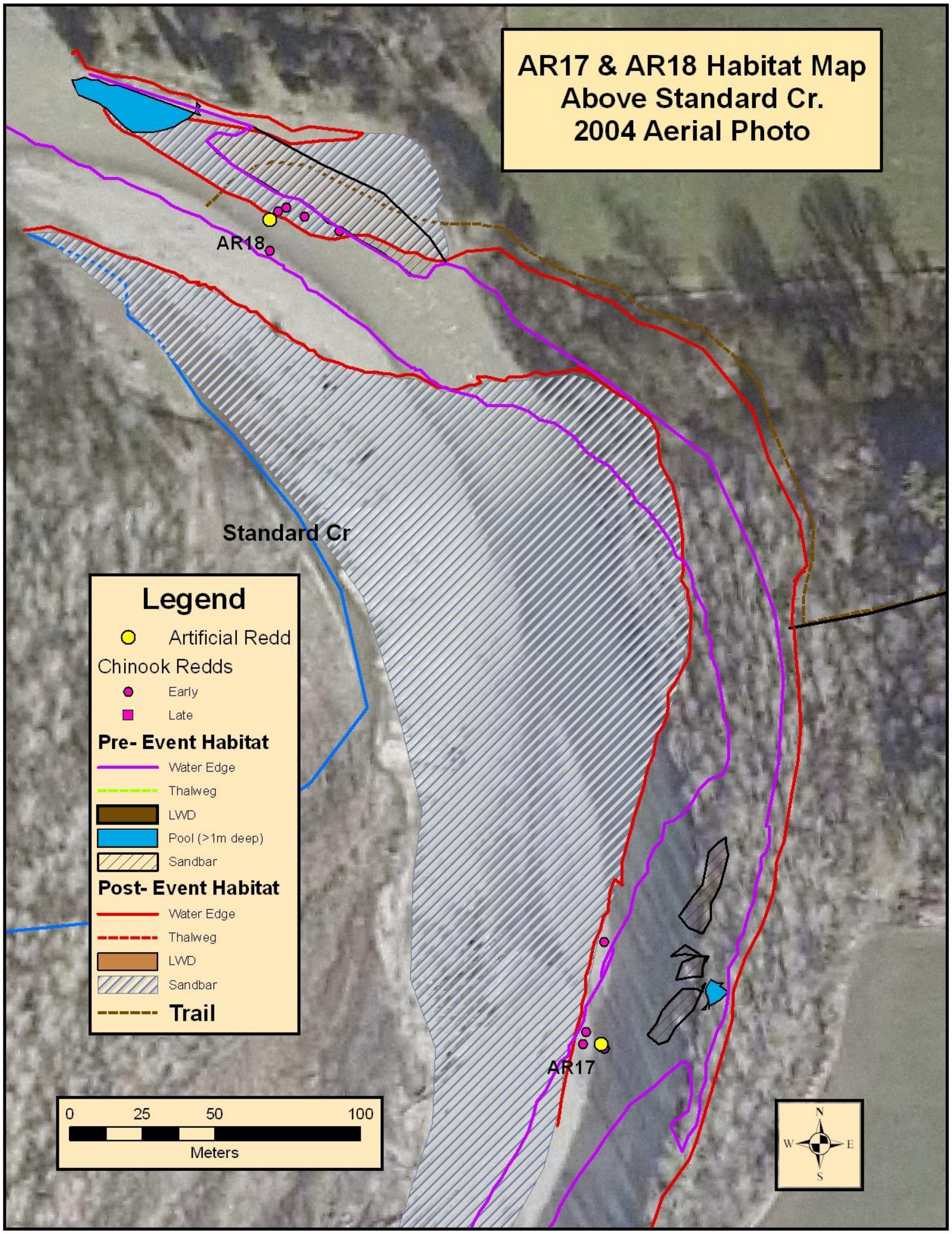


Figure 15. Map showing habitat features at AR17 & AR18 before and after high flow events of 2006/2007 (from Appendix D).

Figure 16. Photo of artificial redd sites AR3 & AR14 above Hutchinson Creek during redd construction where the downstream pool was entirely filled in following high water events in the winter of 2006/2007.

Figure 17. Photo looking upstream of bank erosion at site AR4.

foreground. The artificial redd would be just to the right of the photo. Despite the clear water, we were not able to locate either the redd pocket monitoring tube or the four sediment bag lines.

Sediment Sample Analysis

Of the 22 sediment infiltration bag/frame collection devices installed when redds were constructed; only six samples were located and recovered. A single infiltration cube frame was discovered (without the sample bag) at river mile 15.9, possibly from AR13, 2.4 miles upstream. Table 4 summarizes the sediment infiltration results. Appendix Table E lists the sediment composition and calculates the percent fines <0.85mm for each of the samples.

Two of the recovered samples were removed after redd construction to evaluate conditions at the start of the incubation period. These were at sites AR22 (RM 3.9) and AR14 (RM10.9) adjacent to AR19 and AR3 respectively.

Four other sediment samples were found after the emergance period (early-timed chinook) based on the temperature model. One sample (AR4) was found during the next year's spawning season (9/5/07) and was not processed. The other three "post-event" samples were taken from sites AR12, AR19, and AR21. Note that AR22 and AR19 were located in the same riffle, approximately 1.3 m from each other, parallel to the flow. Retrieval of AR19 was delayed due to high flows, approximately 3 months after the emergance period.

Table 4. Sediment infiltration gravel sample results.

Infiltration Cube Gravel Sample Results

	Early Incubation		**Post-Incubation**		
Site:	**AR14**	**AR22**	**AR12**	**AR19**	**AR21**
Collected:	9/12/06	9/29/06	2/2/07	7/17/07	4/11/07
Stream:	S. Fork	S. Fork	S. Fork	S. Fork	M. Fork
WIRIA:	#'0246	#'0246	#'0246	#'0246	#0339
RM:	10.89	3.87	17.01	3.87	1.80
Sample Total (ml)=	6,176.0	3,552.5	5,604.0	5,763.0	2,471.5
Total<0.85 (ml)=	528.0	136.0	863.5	1494.0	445.0
Percent <0.85=	8.5%	3.8%	15.4%	25.9%	18.0%
Rating=	Good	Good	Fair	Poor	Poor

Both "pre-event" samples had a "good" survival rating, based on Timber Fish & Wildlife (TFW) guidelines (Schuett-Hames, et. al., 1999). In the lower mainstem (RM 3.9) riffle where AR22 and AR19 were located, fine sediment levels started at 3.8% and increased to 25.9 of the sample by volume. This corresponded to a egg incubation survival rate from “good” to “poor”. At site AR12 (RM17.0), where the most number of nearby chinook redds were seen in 2006 (7 redds w/in 25 m radius), survival was rated “fair” based on 15.4% fines in the sample. The single Middle Fork sample had a “poor” survival rating based on 18.0% fines.

Figure 18 is a plot of streamflows throughout the study period. Shown in shaded boxes are periods for early-timed chinook hatching and fry emergance. Also plotted are dates when artificial redds were constructed, when redds were monitored, and dates when gravel sample recovery attempts were made. Dates of major flow events exceeding 4,000 cfs are shown. Dates when gravel samples were retrieved at sites AR12 and AR19 in the S. Fork are shown in orange. It is believed that the high accumulation of fines in AR19 took place primarily during the high flow events, not following the end of the predicted emergance period on 4/13/07.

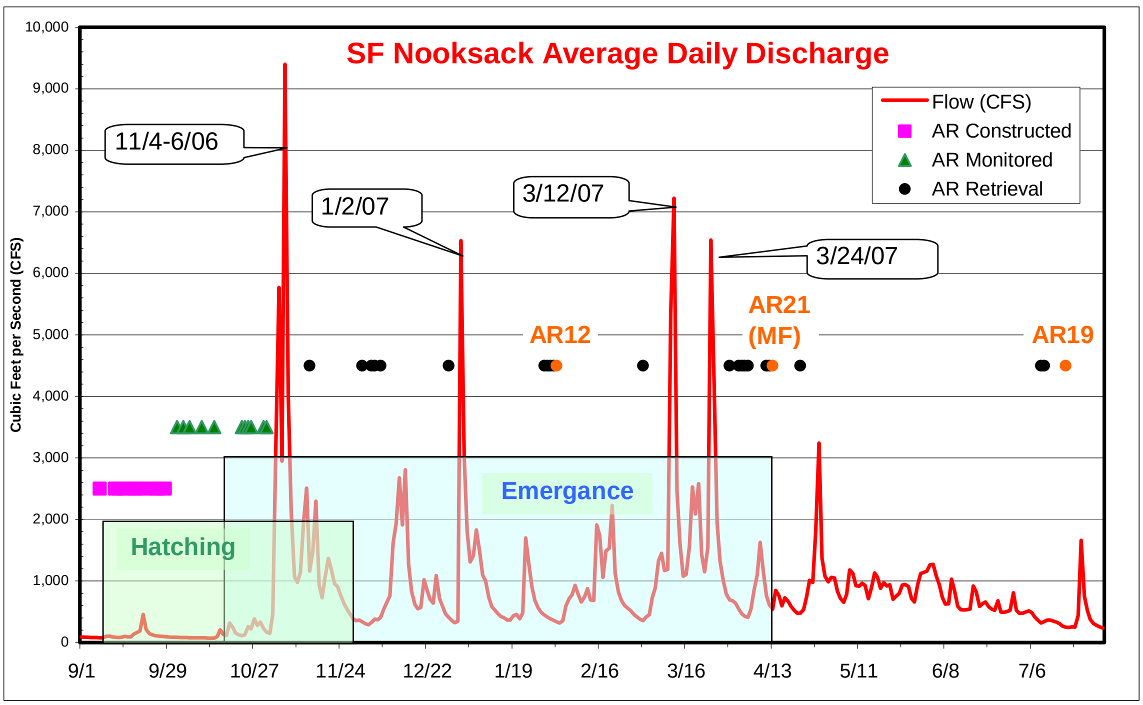


Figure 18. Plot of average daily streamflows for the South Fork Nooksack during the study period. Shown are dates when artificial redds were constructed, monitored and when attempts were made to recover infiltration gravel samples.

Recovering Sample AR12

On 2/2/07 we successfully extracted a complete gravel sample at the AR12 site, known as the “Ford Crossing” at river mile 17.0. We found only the downstream survey pin, but using the tape measurement from this pin and the sub-meter GPS put us within 30 cm of the center of the infiltration cube. Confirming the location of the cube was a strong signal from the magnetic detector. It took some time (approx. 30min.) to carefully excavate 31 cm down into the substrate to the top of the frame. We then had to carefully dig around the frame to locate all four lines attached to the corners of the bag folded under the frame. The lines were carefully pulled upwards by hand causing the opening to slide over the frame enclosing the gravel sample. Figure 19 shows the relationship between water depth, bed depth and frame depth during construction and retrieval of the gravel sample.

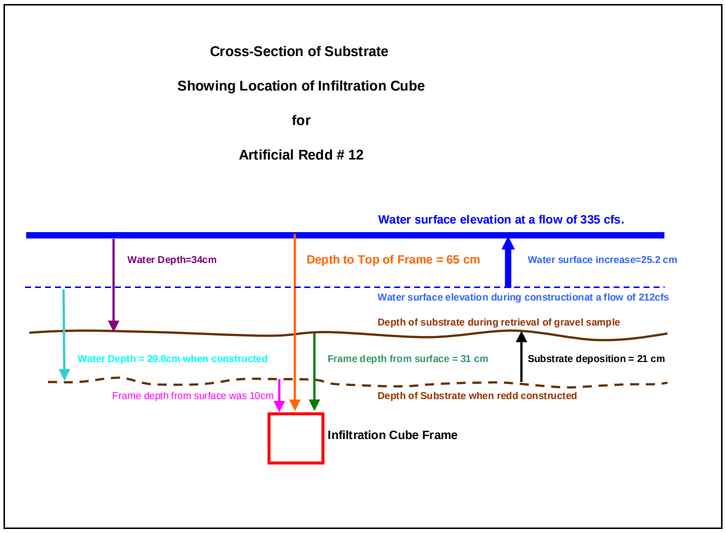


Figure 19. Cross-section of artificial redd site AR12 showing conditions during construction and during retrieval of gravel sample on 2/2/07.

The recovery of the AR12 sample demonstrated the ability of the GPS to navigate to site in the absence of survey pins. We also showed that the magnetic detector was capable of detecting the stainless steel infiltration cube frame to a depth of 31 cm. Based on the vertical position of the cube relative to the bed elevation, it appears that the bed increased in elevation approximately 21 cm at the redd site.

<u>Recovering Sample AR19</u>

As discussed earlier, due to flows which prevented getting to the site, sediment sample AR19 was retrieved approximately 3 months after the end of the emergance period. The high percentage of fines in this sample was probably the result of accumulations during the multiple high flow events prior to the end of the emergance period.

When we eventually arrived at the site on 4/11/07, no survey pins could be found. As with AR12 we relied on the GPS to navigate to the site. Clear water conditions and the exposed frame protruding from the streambed allowed us to easily locate the sample. The spot indicated by the GPS was further away from the actual site than expected, which would have probably resulted in missing the sample if it had not been exposed. The GPS location was 1.4 m from the center of the exposed frame, on a diagonal slightly upstream towards the left bank.

The top of the frame was exposed 5 cm above the bed elevation. The frame was in its original vertical orientation, indicating that it had not been tilted or moved from its original location. At the time of installation, the top of the frame was 11 cm below the bed elevation. This indicates an overall scour of 16 cm at this location. If this had been an actual redd, the egg pocket area would probably still have remained intact. Whether the eggs would have received sufficient oxygen to survive hatching would be the more important factor affecting survival at this location.

Recovering Sample AR4

Sediment bag and frame of AR4 was discovered a year later (9/7/07) during a routine spawning ground survey when flows were very low (127cfs). The top of the frame was exposed from the streambed approximately 9 cm. The frame was found vertical tilted and apparently not moved from its original position. The bag and sediment sample was removed but not processed due to the long period that existed beyond the emergance period.

Frame Found below Dyes Canyon

An infiltration frame was found at the outlet of Dyes Canyon at river mile15.9. It was resting near the waters edge on the left bank. The next site upstream where no frame had been found was AR13 at RM18.3, approximately 4.4 miles upstream. .

Chinook Fry at AR20

On 4/4/07 we visited site AR20 (river mile 19.3) a second time in an attempt to find the infiltration gravel sample, but instead found approximately 30 chinook fry in the isolated pool formed from our excavation on the previous day (Figure 21). During the winter flows, a new sandbar had completely covered the AR site, which was built near the thalweg the previous fall (see habitat map in Appendix D4. Lengths of the fry measured between 38 - 41 mm. **The body shape was slender, possibly indicating an emaciated condition**, and the yolk sac was entirely absorbed. Based on our temperature development model (calculation of development based on surface water temperature using published “temperature units” for chinook) these were **most likely Fall-timed chinook**. It is doubtful that these fry would have the energy reserves needed to travel subsurface laterally the 50 m distance to the wetted channel. Higher flow conditions could have covered the bar making vertical passage by the fry through the gravel to the river possible. To allow these fry to escape to the river, we provided a connection from the excavation pit to a small slough which was carrying percolating river water as can be seen in the second photo.

Figure 20 Photos of artificial redd site AR20 looking downstream. Upper photo shows the wetted edge approximately 50 meters to the right from its original location. Lower photo shows excavation area and standing water where chinook fry were found. Note ~25' channel dug to connect to small slough to allow chinook to escape to the river.

Discussion

<u>Artificial Redd Survival</u>

Table 5 summarizes the results for all artificial redds constructed in the South Fork Nooksack. Five sites were not evaluated because or they could not be located due to missing survey pins, poor GPS reception, and water too swift to access the site, possible vandalism or were outside the South Fork (AR21).

Of the remaining 16 sites, AR20 and AR11 were buried with coarse gravel (> 0.5 m above frame) to an extent that would have compromised emergence. One site (AR19) yielded a gravel sample that had a very high level of fine sediments (25.9% fines < 0.85mm) indicating poor survival due to egg suffocation. Another site (AR12) had sediment with a moderate level of fines (8.5%) indicating "fair" survival. The sediment sample bag and frame (AR4) found late during the next spawning period was presumed to have fair survival because it was not removed by scour, but the sediment sample was not processed.

Failure to recover frames at the other 11 sites, despite extensive searching efforts, indicates redd scour may have been present sufficient to destroy most or all of the eggs in the redd. We estimate that redd scour may have affected approximately 69% of the artificial redds in our South Fork sample. This is not unlikely, given an over-winter period that had the 6th highest flow event in a 30-year gage record. Figure 21 is a map showing the location and fate of artificial redds constructed in the South and Middle Forks in 2006.

Table 5. Summary of artificial redd results.

Artificial Redd Results

Artificial Redd Sites	Survival	Redds	Percent
AR20, AR11	Poor Survival due to redd burial > 0.5 m	2	12.5%
AR19	Poor Survivial due to fine sediment infiltration	1	6.3%
AR12	Fair Survival due to fine sediment infiltration	1	6.3%
AR4	Fair Survival (no scour, unknown fine sediment)	1	6.3%
AR18,17,7,9,3,14,6,5,13,1,2	Poor Survival due to presumed redd scour	11	68.8%
		---	------
	S. Fork Sample Size (N) =	**16**	**100.0%**
AR16, AR10	Unable to Locate (missing pins / poor GPS)	2	
AR15	Unable to Locate (site too swift)	1	
AR8	Unable to Locate (possible vandalism)	1	
AR21	Middle Fork Redd	1	

	Total Redds Constructed =	**21**	

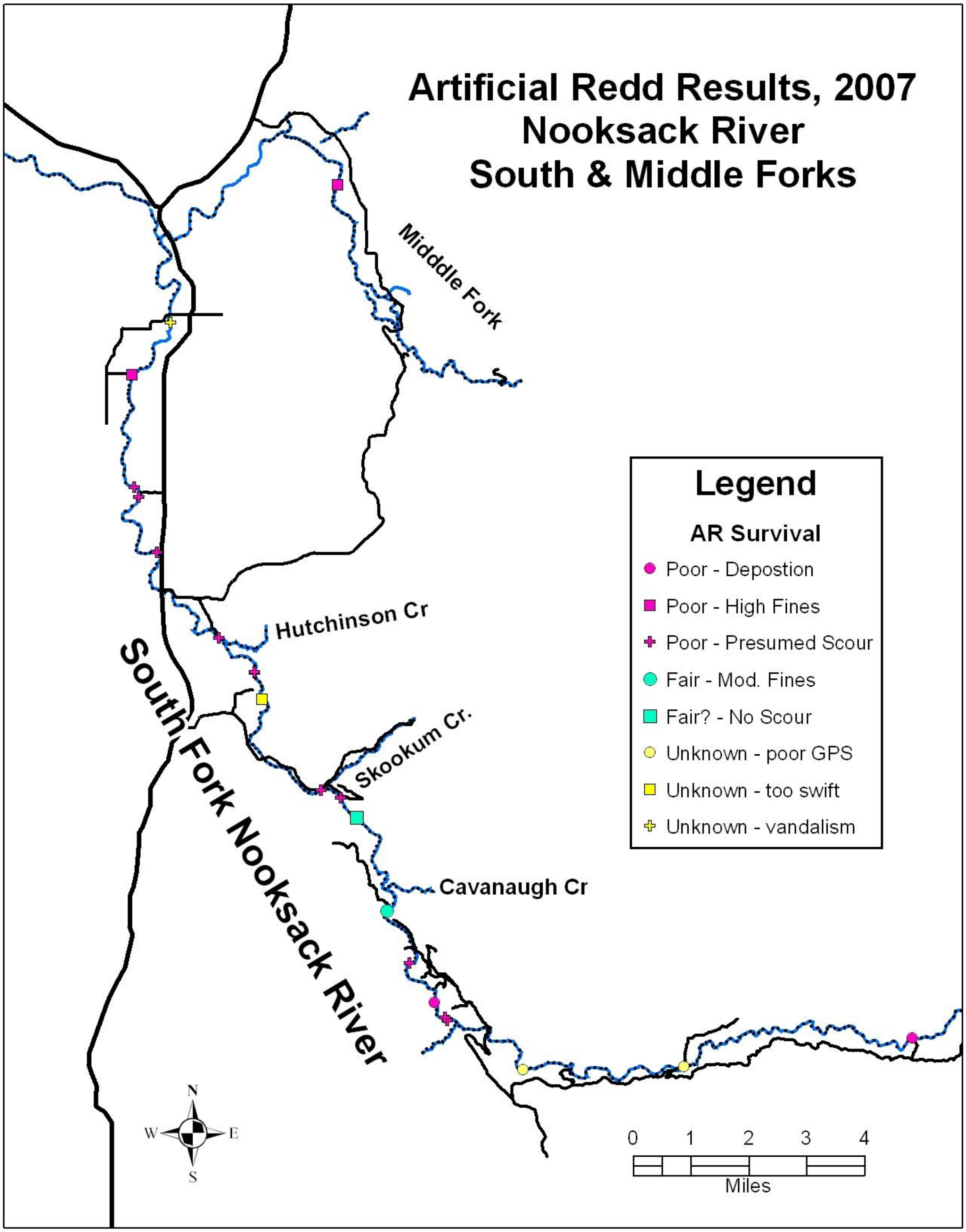


Figure 21. Map of post-emergance artificial redd observations in 2007.

Locating Artificial Redds and Implications for Detecting Redd Scour

Monitoring and sediment sample retrieval relies on accurately locating each artificial redd. In this study, because we did not have vertical control at each site, redd scour was indicated by an inability to re-locate the metal infiltration cube frame.

At the start of this endeavor, we anticipated AR re-location to be challenge so various methods were used. Prior to the significant flow event of 11/6/06, all redds except one could be located visually by finding the infiltration bag lines and the exposed monitoring tubes. Water depth and turbidity are related and both important for visually locating the redd site using these references. When lines could not be seen it was necessary to first locate the survey stakes on the bank and measure the distance to the site from each stake. Unfortunately we located some stakes too close to the site and they were lost due to channel shifting and bank erosion.

When one or both stakes were found missing, the AR site could be navigated to using the "sub-meter" GPS unit. However, poor GPS reception caused problems at some sites. One location in the upper watershed (AR10) is in a narrow canyon, which prevented acceptable satellite coverage. Site AR5 also had poor reception, possibly due to a nearby steep bank.

Of the two gravel samples that were found, navigating using the GPS put us within 30 cm of the center of AR12. The apparent GPS error for the downstream recovered sample AR19 was much larger, 140 cm from the center of the cube, possibly due to the effects of nearby tall trees on the left bank. Had the infiltration cube frame not been visible at this location, it is likely that the site would have been given a missing status indicating redd scour. In this example the metal detector may not have provided sufficient indication of a buried cube, due to the large number of false positive signals from iron containing rocks that were noted at some locations. It was affirming, however that AR12, on the other hand, gave a strong signal with the metal detector even though the cube was buried below the substrate 31 cm.

Streamflow Constraints

As expected, river discharge proved to be the single most important factor limiting our ability to conduct field activities. Experience gained in the 2006 / 2007 field season showed that the construction of artificial redds required flows below approximately 225 cfs. Hyporheic monitoring of the egg pockets during the critical incubation period (from mid September until mid-December) proved difficult where flows exceeded 260 cfs. Recovery of the infiltration cube / sediment samples appeared to be the most tolerant activity, but required flows less than approximately 450.

In 2006 it required 13 days field days to construct 21 artificial redds. Monitoring all redds on a bi-weekly basis took 8 field days. Most monitoring occurred within the first third of the egg incubation period (10/8 to 12/12). Due to flows, monitoring was not possible in critical last third of the monitoring period (11/21 to 12/12).

Figure 22 is a plot of S. Fork discharges from 1999 – 2007 with colored boxes indicating periods and flows necessary for redd construction, redd monitoring, and gravel sample recovery.

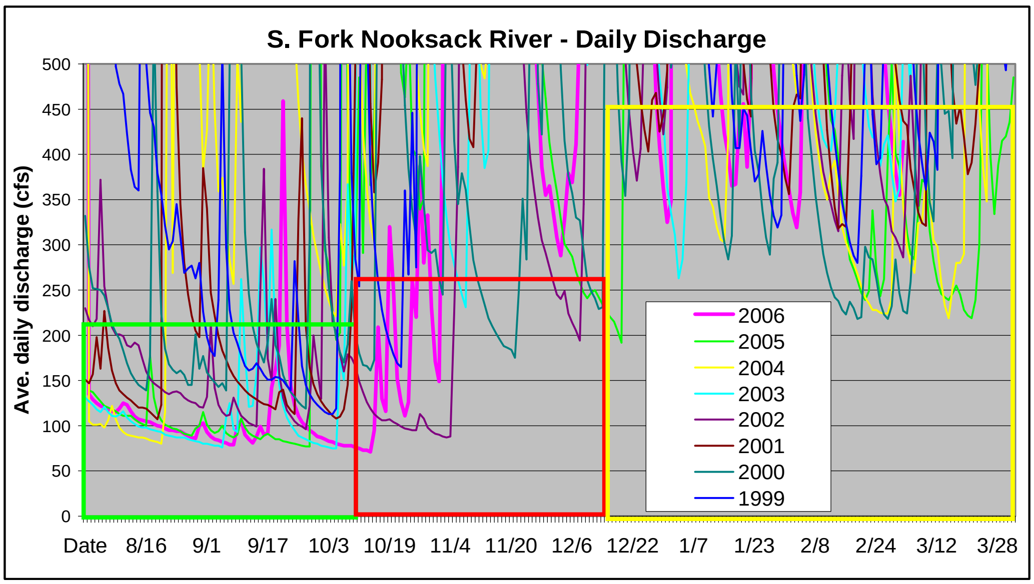


Figure 22. Plot of South Fork Nooksack average daily discharge from August 1st to March 31st, 1999-2007. Colored boxes indicate periods and maximum flows needed to construct artificial redds (green box), monitor hyporheic water (red box), and retrieve gravel samples (yellow box).

Using these streamflow records, Table 6 is a count of suitable field days where flows did not exceed the upper flow limits for these activities. This suggests that on average, only 13 field days would have flows suitable for monitoring during the incubation period. During the critical last third of this period, when hatching occurs and DO demands are the greatest, only **2 field days** on average would be suitable, based on historic streamflow records. Future study plans should not expect more than brief periods to monitor redds unless techniques can be developed to increase the flow dependant field "window". Extending the length of sampling tubes and increasing their visibility are two modifications that might extend sampling period into days with higher flows.

Table 6. Count of field days, based on historic flow records, with average daily flows below demonstrated limits for artificial redd construction, egg pocket monitoring, and retrieval of the infiltration sediment sample.

Count of Field Days with Acceptable Streamflows for Artificial Redd Field Activities, 1999 - 2006

Field Activity	Max Flow (cfs)	Field From	Dates To	Days Available	Field Days with Allowable Streamflows 2006	2005	2004	2003	2002	2001	2000	1999	8-Year Average
Construct Artificial Redds	225	8/1	10/7	68	67	62	26	65	58	53	44	29	51
Monitor Egg Pockets	260	10/8	12/12	66	21	5	0	5	38	3	22	8	**13**
Retrieve Gravel Sample	450	12/12	3/31	110	25	53	49	21	25	31	56	31	36

Conclusions & Recommendations

Conclusions

1. Methods used to construct artificial redds, sample interstitial egg pocket water, locate and retrieve infiltration gravel samples from the artificial redd were demonstrated successfully.

2. With the extended period of very low flows in 2006, it was possible to construct 20 artificial redds, replicating the approximate distribution of chinook redds observed in the South Fork Nooksack.

3. The peak flow events on and after 11/6/06 caused major channel shifting, streambed scouring, and gravel deposition at most artificial redd locations. As a result only two of 20 gravel samples were recovered, indicating poor chinook survival in 2006/2007 during the egg-to-fry life stage for early-timed chinook.

4. Egg pocket water sampling during the first two-thirds of the incubation period for early-timed chinook indicate good overall DO levels were present with the exception of site AR2 where high conductivity and lower relative DO values indicated the presence of groundwater. At other sites, evidence of groundwater in the egg pockets was not detected.

5. Extreme low flow conditions during the redd construction period led to redds being located lower in the stream channel which hampered later recovery efforts which were took place at somewhat higher flow levels. We found that monitoring water within the egg pockets is practical only during short periods when the flows are less than approximately 250 cfs. Recovery of infiltration cubes is feasible only at flows below approximately 450 cfs.

6. Multiple methods were necessary to locate artificial redds. These techniques must be precise (within ~25 cm radius) to recover gravel samples, which have not been lost to scour. We combining sub-meter GPS positioning, measured distances to survey stakes, and the use of a metal detector to find infiltration cubes at artificial redd sites.

7. Recovery of some infiltration cubes may have been hampered by an inability to excavate to a sufficient depth to expose the frame in cases where there was an increase in the bed elevation due to sediment deposition at the redd site. At a few sites, higher flows during the recovery period caused water depths greater than 0.5 m and high velocities which reduced our ability to excavate to our goal depth of 30 cm below bed elevation.

Recommendations

1. Each artificial redd site should have its bed elevation surveyed and tied to a safe benchmark, located some distance from erodable banks. As flows allow, additional bed elevation measurements should be taken during the egg incubation period at each site. Following expected emergance, a final elevation should be taken.

2. When marking artificial redds, use duplicate rebar stakes upstream and downstream of site placed a minimum of 2 meters from eroding banks.

3. Due to the likelihood of limited opportunities to monitor redds, especially the most important last third of the incubation period, plan on visiting fewer sites in areas of high chinook spawning activity, that can be accessed without the need to cross the stream channel.

4. To improve our ability to locate artificial redds for monitoring, sampling tubes should be longer (60-80 cm long) and painted with a bright color. Infiltration bag lines should be of a bright buoyant material such as polypropylene to reduce likelihood of the lines becoming entirely buried by gravel during high flow events.

5. Consider inserting iron balls, re-bar, or metal plates in proximity to the artificial redd to enhance detection using a metal detector. Care should be given so as to not alter sediment infiltration rates in the sample as a result of these enhancements.

6. To avoid heating the water sample drawn from the sampling tube with the bulb-type hand pump, position the pump below the waters surface while pumping.

Acknowledgements

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Appendix A. Artificial redd characteristics, 2006.

Artificial Redd Charactistics, 2006

Redd ID #	Location	RM	Stake Dist. Upstr	Stake Dist. Dwnstr	Frame Depth (cm)	Redd L (m)	Redd W (m)	Redd D (cm)	Water Vel (m/s)	Substr. Dom (cm)	Substr. SubD (cm)	Substr. % Dom	Holding Habitat Type	Up/ Dwn	Dist(M)	Paces
AR8	Above Potter Br.	2.03	14	41.3	9.0	1.6	1.1	23.0	0.60	8	5	60%	RB cedar RW	D	66.5	95.0
AR19	Below Sygotowitz Cr.	3.87	73.2	69.8	11.0	3.0	1.2	25.0	0.86	11	6	60%	N/A	N/A	N/A	
AR18	Standard Creek, dwnstr.	6.20	55.8	58.8	12.0	2.5	1.3	38.7	0.63	10	5	70%	RB logjam	D	56.0	80.0
AR17	Standard Creek, upnstr.	6.36	62.3	63.8	14.0	1.5	1.0	29.5	0.38	6	6	70%	RB logs	D	45.5	65.0
AR7	Above RR Bridge	7.83	36.5	20	9.0	3.2	1.6	37.0	0.64	8	4	60%	LB log pool	D	56.0	80.0
AR9	Hutchinson Cr. dwnstr.	10.05	63.2	58.5	8.0	2.5	1.3	32.2	0.50	13	6	70%	RB ww riffle	D	28.0	40.0
AR3	Above Hutchinson Cr.	10.89	36.6	44.3	N/A	2.9	1.4	26.0	0.60	14	6	70%	LB logjam	D	22.4	32.0
AR14	Above Hutchinson Cr.	10.89	41.4	29.2	9.5	2.4	1.0	29.8	0.53	13	7	80%	LB logjam	D	22.4	32.0
AR15	Below Saxon Creek	11.48	N/A	N/A	5.5	3.2	1.4	26.5	0.80	13	6	80%	LB ww pool	D	5.6	8.0
AR6	Below Skookum Wier	14.17	29.9	29	N/A	2.8	1.5	16.0	0.56	8	4	60%	LB boulder pool	D	33.6	48.0
AR5	Skookum Hole	14.52	39.7	N/A	9.0	1.4	1.6	28.0	0.28	14	7	70%	RB bdrx pool	D	32.2	46.0
AR4	Above Stream Gage	14.92	35.7	27.5	8.0	3.4	1.7	30.0	0.57	13	6	60%	RB brush hole	D	10.5	15.0
AR12	Ford Xing	17.01	39.1	54	10.0	2.7	1.5	29.8	0.60	8	5	70%	LB bedrx pool	U	84.0	120.0
AR13	Above RM 18 Bridge	18.31	17	21.9	10.0	3.0	1.2	36.5	0.60	8	6	60%	LB logjam	U	21.0	30.0
AR20	Above Eagle Nest	19.33	24.2	21	12.0	3.0	1.4	25.8	0.43	5	7	70%	log/whitewater	D		
AR1	Above Plumbago Cr, LB	19.78	25.1	25.3	N/A	3.4	1.7	8.0	0.38	N/A	N/A	N/A	N/A	N/A	N/A	N/A
AR2	Above Plumbago Cr, RB	19.73	35.6	43.2	N/A	2.8	1.6	25.0	2.50	N/A	N/A	N/A	N/A	N/A	N/A	N/A
AR16	Above Larson's Bridge	21.86	42.2	37.6	9.0	2.8	1.0	22.3	0.51	8	5	70%	LB boulder pool	D	12.6	18.0
AR10	Above 200 Bridge	24.90	30.8	39.9	N/A	3.3	1.3	32.0	0.55	2	4	80%	lg bedrx pool	U	35.0	50.0
AR11	Above 330 Bridge	29.94	42.3	63.8	11.0	3.0	1.0	26.0	0.60	9	5	70%	RB br. Footing	D	17.5	25.0
AR21	M. Fork, Rutzatz Rd.	1.80	23.6	15.1	N/A	2.3	1.2	16.0	0.58	9	5		N/A	N/A	N/A	N/A
					Ave.=	**2.7**	**1.3**	**26.8**	**0.7**	**9.5**	**5.5**				**34.3**	

Appendix Table B. Chinook redd characteristics in proximity to artificial redds in 2006.

Chinook Redd Characteristics
in Proximity to Artificial Redds in 2006

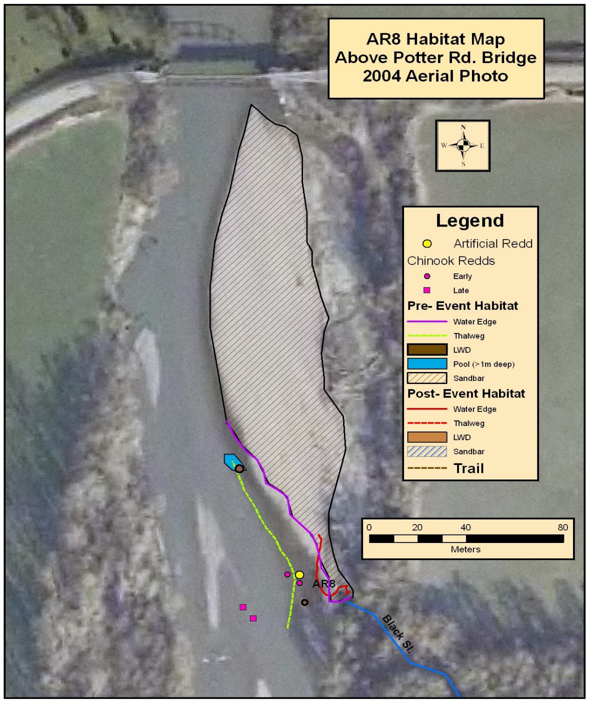
2006 Survey Date	Nearest Art. Redd	Redd ID	Date First Observed	River Mile	Stream Bank	Redd L (m)	Redd W (m)	Redd D (cm)	Water Velocity (m/sec)	Dominant Substrate Particle (cm)	Sub-Dominant Substrate Particle (cm)	Dominant Particle Percent Area	Nearby Holding Habitat	Direction Upstream/ Downstr.	Distance to Holding Habitat (m)	Habitat Notes:
9/11	AR9	MM01	9/11	10.29	L	4.3	1.7	44.8	0.5	N/A	N/A	N/A	N/A	N/A	N/A	
9/11	AR9	JB02	9/11	10.29	L	4.5	1.6	24.5	0.5	N/A	N/A	N/A	N/A	N/A	N/A	
9/11	AR9	MM02	9/11	10.29	M	4.8	1.6	28.3	0.6	8	1	80%	N/A	N/A	N/A	
9/12	AR3	RR03	9/12	10.80	R	4.1	1.3	37.5	0.6	12	6	70%	RB bedrx pool	D	21.0	
9/12	AR3	MM01	9/12	10.80	R	7.1	1.7	24.8	0.6	15	3	60%	RB bedrx pool	D	N/A	
9/12	AR3	RR02	9/12	10.90	L	2.1	1.5	28.8	N/A	12	5	80%	LB logjam pool	D	N/A	
9/13	AR4	AP03	9/6	14.96	R	5.5	2.1	35.0	0.8	16	6	70%	LB RW/log pool	U	36.4	
9/13	AR4	MM01	9/13	14.92	R	9.0	1.7	25.0	0.8	13	6	60%	RB brush hole	D	10.5	pool D=0.8m
9/13	AR5	AP04	9/6	14.52	L	5.9	2.9	29.3	0.7	14	7	70%	RB bedrx pool	D	32.2	"Skookum Hole"
9/13	AR6	AP01	9/13	14.18	L	4.0	2.6	22.5	0.4	7	4	60%	LB boulder hole	D	33.6	pool D=1.0m
9/15	AR8	MM01	9/15	2.02	R	9.2	1.8	37.5	0.9	7	3	60%	RB cedar RW	D	66.5	pool D=1.1m
9/18	AR6	TM01	8/21	13.16	L	4.5	1.8	18.0	0.8	6	3	80%	LB boulders	D	91.0	pool D=2.0 m
9/18	AR6	MM01	9/18	13.16	L	3.0	1.3	22.0	0.6	9	6	90%	LB boulders	D	91.0	pool D=2.0 m
9/18	AR6	TM06	8/21	13.16	L	6.0	1.8	38.5	0.8	10	4	80%	LB boulders	D	91.0	pool D=2.0 m
9/18	AR6	TM02	8/21	13.16	L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
9/18	AR6	MMO1	9/18	8.70	M	6.7	2.4	43.0	1.0	17	6	80%	RB riffle white w.	D	28.0	
9/18	AR6	MM02	9/18	8.65	L	4.3	2.5	53.5	0.5	7	10	60%	RB riffle white w.	D	67.9	
9/19	AR10	MM01	9/19	24.90	L	3.5	2.2	45.0	0.6	2	4	80%	RB/LB bedrock	U	35.0	
9/22	AR12	TM02	8/31	17.00	M	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	poor vis. = 56 cm
9/22	AR12	AP03	9/15	18.30	R	N/A	N/A	N/A	N/A	N/A	N/A	N/A	LB logjam hole	U	21.0	
9/22	AR12	MM01	9/22	18.30	R	N/A	N/A	N/A	N/A	N/A	N/A	N/A	LB logjam hole	U	21.0	
9/22	AR12	MM02	9/22	18.26	L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	LB logjam hole	U	N/A	
9/25	AR14	MM01	9/25	10.90	L	3.6	1.7	28.8	0.6	13	7	80%	LB logjam hole	D	21.7	female digging redd
9/25	AR14	MM02	9/25	10.90	R	3.6	3.0	34.5	0.5	13%	6%	80%	LB logjam hole	D	12.6	
9/25	AR14	MM03	9/25	10.90	L	8.3	3.0	17.3	N/A	N/A	N/A	N/A	LB logjam hole	D	N/A	female digging redd
9/25	AR15	MM04	9/25	11.49	R	7.0	1.9	17.0	1.0	13.0	6.0	80%	LB whitewater	D	3.5	
9/25	AR15	JB3	9/20	11.90	L	6.0	1.7	22.3	0.8	10	7	80%	LB whitewater	D	14.0	
9/26	AR16	MM01	9/26	21.10	L	7.5	2.6	22.5	0.9	17	7	90%	LB woody pool	D	17.5	1 live chinook
9/26	AR16	AP02	9/7	21.52	M			0.0							0.0	
9/26	AR16	AP03	9/7	22.03	M	3.2	1.1	31.0	0.6	9	5	70%	LB boulder pool	D	13.3	
9/26	AR16	AP04	9/7	22.04		8.0	2.0	50.8	1.0	9	6	70%	LB boulder pool	D	21.0	
9/26	AR16	MM02	9/26	21.62	R	3.0	1.5	20.5	0.6	8	5	70%	LB claybank hole	U	24.5	
9/26	AR16	AP01	9/7	21.88	R			0.0							0.0	GPSed only
9/28	AR17	RR07	9/25	6.36	L	6.8	4.0	20.8	0.7	10	5	70%	RB logs	D	45.5	5' deep
9/28	AR17	RR08	9/25	6.33	L	4.6	3.0	0.0	0.8	12	6	70%	RB logs	D	45.5	
9/28	AR18	MM03	9/28	6.20	L	6.0	2.3	30.8	0.8	6	10	70%	RB logjam	D	56.0	8' deep
9/28	AR18	RR09	9/25	6.20	R	6.0	6.0	22.8	0.9	9	5	70%	RB logjam	D	56.0	
9/28	AR18	MM01	9/28	6.20	R	4.8	2.0	34.3	0.6	9	5	70%	RB logjam	D	56.0	3 live chinook
9/28	AR18	MM02	9/28	6.20	R	6.0	6.0	19.3	0.9	7	5	70%	RB logjam	D	56.0	
9/28	AR19	RR02	9/26	3.80	M	9.0	7.0	22.0	1.0	10	5	70%	LB log pool	D	28.0	1 live chinook
9/28	AR19	RR03	9/26	3.78	R	8.0	8.0	33.3	1.3	9	5	60%				
9/29	AR21	AP09	9/11	1.76	L											
9/29	AR21	AP08	9/11	1.76	L											
9/29	AR19	MM01	9/29	3.80	M	6.0	1.9	25.0	0.9	9	6	60%				
10/2	AR8	MM01	10/2	2.02	M	7.0	2.0	24.5	0.8	7	5	70%	cedar rootwad	D	56.0	1 live chinook
10/2	AR8	MM02	10/2	2.02	L	4.6	1.7	20.8	0.7	7	5	70%	cedar rootwad	D	73.5	
10/2	AR8	MM03	10/2	2.02	R	5.0	1.7	32.0					cedar rootwad	D	73.5	
10/2	AR7	MM04	10/2	7.80	L	3.0	1.2	35.8	1.0	6	3	70%	LB log pool	D		
10/2	AR7	MM05	10/2	7.80	L	5.2	1.9	49.5	1.0	4	2	70%	LB log pool	D		
					Ave.=	**5.5**	**2.5**	**27.9**	**0.8**	**9.4**	**5.1**	**72%**			**38.8**	

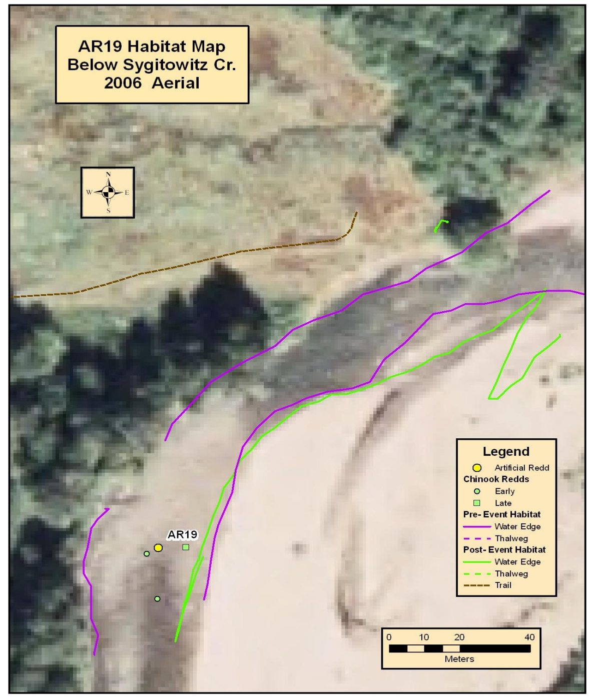
Appendix C. Artificial redd monitoring data, 2006.

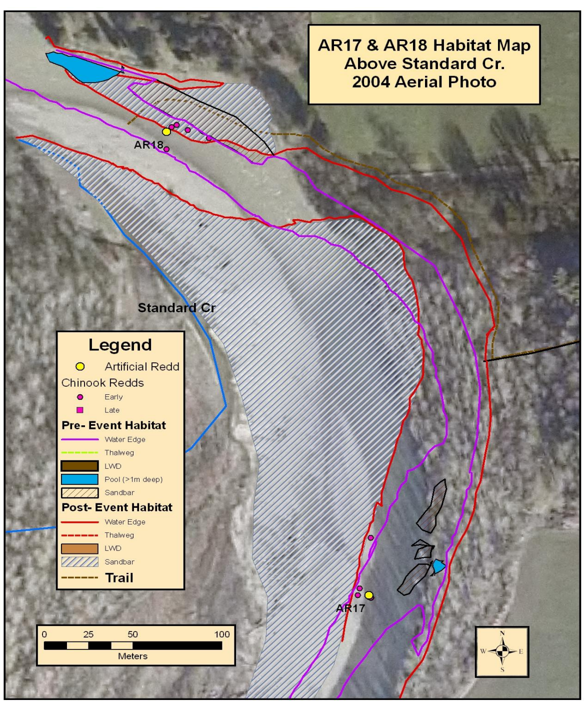
Artificial Redd Monitoring Data - 2006

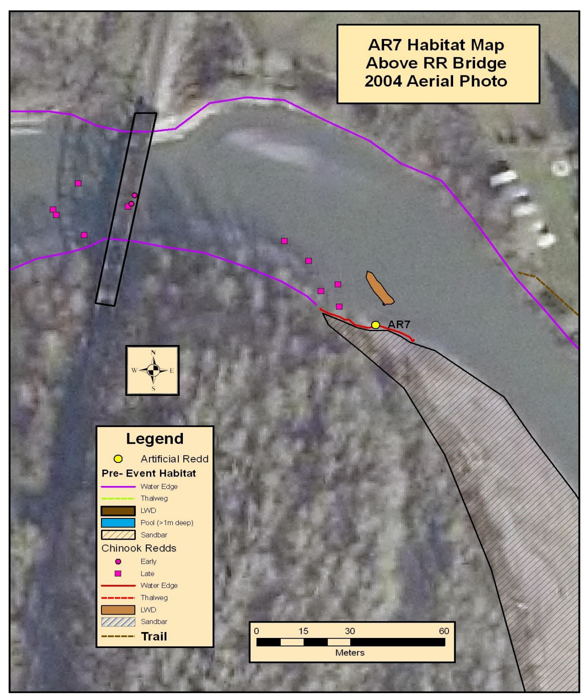
Art. Redd ID	River Mile	Location	Date	River Water Temp (C)	River Water Cond. (uS)	River Water DO (ppm)	Egg Pocket Temp (C)	Egg Pocket Cond. (uS)	Egg Pocket DO (ppm)	Pump Time (s)	Pump Type
AR8	2.03	Above Potter Br.	10/2	11.0	119.9	9.7	11.3	126.0	**9.7**	N/A	crank
AR19	3.87	Above Sygotowietz Cr.	10/2	11.5	124.0	11.2	11.7	123.8	11.1	N/A	crank
AR18	6.20	Standard Cr., Dwnstr.	10/2	11.6	121.1	11.3	11.8	120.8	11.0	N/A	crank
AR17	6.36	Standard Cr., Upstr.	10/2	11.6	120.7	11.3	11.9	119.9	11.0	N/A	crank
AR7	7.83	Above RR Bridge	10/2	12.2	119.2	11.3	11.9	117.9	10.7	N/A	crank
AR9	10.05	Hutchinson Cr. dwnstr.	10/2	**12.6**	110.0	11.9	12.7	111.0	9.0	N/A	crank
AR3	10.89	Above Hutchinson Cr.	10/4	10.8	110.5	12.1	11.6	107.0	10.8	N/A	crank
AR3	10.89	Above Hutchinson Cr.	10/4	11.7	108.0	12.1	11.5	107.0	10.8	N/A	electric
AR14	10.89	Above Hutchinson Cr.	10/4	11.5	58.0	12.1	12.4	53.0	11.6	N/A	crank
AR14	10.89	Above Hutchinson Cr.	10/4	11.8	103.0	12.1	11.5	106.0	11.1	N/A	electric
AR15	11.48	Below Saxon Cr.	10/4	12.5	114.0	12.1	**14.0**	116.0	11.7	N/A	crank
AR6	14.17	Below Skookum Cr.	10/4	11.1	114.0	12.4	12.6	114.3	11.9	N/A	crank
AR5	14.52	Skookum Hole	10/4	10.8	115.7	12.2	13.1	123.0	11.0	N/A	crank
AR4	14.92	Above Stream Gage	10/4	11.4	115.0	12.1	12.5	116.0	11.7	N/A	crank
AR12	17.01	Ford crossing	10/6	12.3	112.0	10.7	12.8	114.5	10.5	8	bulb
AR13	18.31	Upstr. RM18 Bridge	10/6	12.1	107.0	10.9	12.1	109.0	10.3	7	bulb
AR20	19.33	Above Eagle Nest	10/10	9.1	111.5	12.5	9.8	113.0	12.3	4	bulb
AR2	19.73	Below Larson's Br, RB	10/10	8.7	112.2	12.6	10.1	115.2	11.6	4	bulb
AR1	19.78	Below Larson's Br, LB	10/10	9.6	113.5	12.4	9.9	114.0	12.1	5	bulb
AR16	21.86	Above Larson's Br.	10/10	9.7	74.9	12.1	10.5	112.5	9.1	12	bulb
AR10	24.90	Above 200 Rd. Br.	10/11	7.5	112.5	12.8	8.3	116.0	11.2	5	bulb
AR11	29.94	Above 330 Rd. Br.	10/11	7.3	98.0	12.6	9.6	102.0	10.6	7	bulb
AR8	2.03	Above Potter Br.	10/23	7.6	115.0	10.6	8.5	116.0	8.5	5	bulb
AR19	3.87	Above Sygotowietz Cr.	10/23	N/A	N/A	N/A	N/A	N/A	N/A	N/A	bulb
AR18	6.20	Standard Cr., Dwnstr.	10/23	8.0	112.0	11.7	8.3	103.0	10.8	6	bulb
AR17	6.36	Standard Cr., Upstr.	10/23	7.9	111.5	11.8	8.4	112.1	11.5	5	bulb
AR7	7.83	Above RR Bridge	10/23	8.2	111.5	11.9	8.3	111.6	10.4	6	bulb
AR9	10.05	Hutchinson Cr. dwnstr.	10/23	8.5	107.4	12.3	9.4	108.0	11.7	11	bulb
AR3	10.89	Above Hutchinson Cr.	10/23	8.9	104.8	12.2	9.3	105.3	10.3	5	bulb
AR14	10.89	Above Hutchinson Cr.	10/23	8.9	104.8	12.2	9.2	104.5	10.5	8	bulb
AR15	11.48	Below Saxon Cr.	10/23	N/A	N/A	N/A	N/A	N/A	N/A	N/A	bulb
AR6	14.17	Below Skookum Cr.	10/23	7.4	106.2	12.5	8.5	105.7	11.5	16	bulb
AR6	14.17	Below Skookum Cr.	10/25	7.0	151.0	12.3	8.0	120.0	11.3	8	bulb
AR5	14.52	Skookum Hole	10/26	7.4	63.0	12.4	7.8	84.0	12.2	5	bulb
AR4	14.92	Above Stream Gage	10/26	7.4	107.8	12.6	7.8	110.6	11.1	5	bulb
AR12	17.01	Ford crossing	10/24	7.0	107.8	12.6	8.2	108.0	11.7	18	bulb
AR13	18.31	Upstr. RM18 Bridge	10/24	7.2	105.2	12.7	7.3	105.0	11.7	6	bulb
AR20	19.33	Above Eagle Nest	10/24	7.3	104.6	12.9	7.8	105.6	12.4	6	bulb
AR2	19.73	Above Plumbago Cr, RB	10/24	7.2	105.0	12.9	8.6	228.0	**7.5**	5	bulb
AR1	19.78	Above Plumbago Cr, LB	10/24	7.8	89.0	12.5	7.9	127.0	12.1	6	bulb
AR16	21.86	Above Larson's Br.	10/31	2.4	90.2	14.0	4.9	49.9	10.5	16	bulb
AR10	24.90	Above 200 Rd. Br.	10/31	2.8	89.4	13.9	3.9	94.5	10.7	5	bulb
AR11	29.94	Above 330 Rd. Br.	10/31	3.0	79.4	13.1	6.3	40.6	11.2	7	bulb
AR21	1.80	M. Fork, Rutzatz Rd.	10/26	7.4	114.0	12.8	7.6	113.6	12.4	5	bulb

Appendix D1 Habitat Maps for Sites AR8, AR19, AR17/18, and AR7.

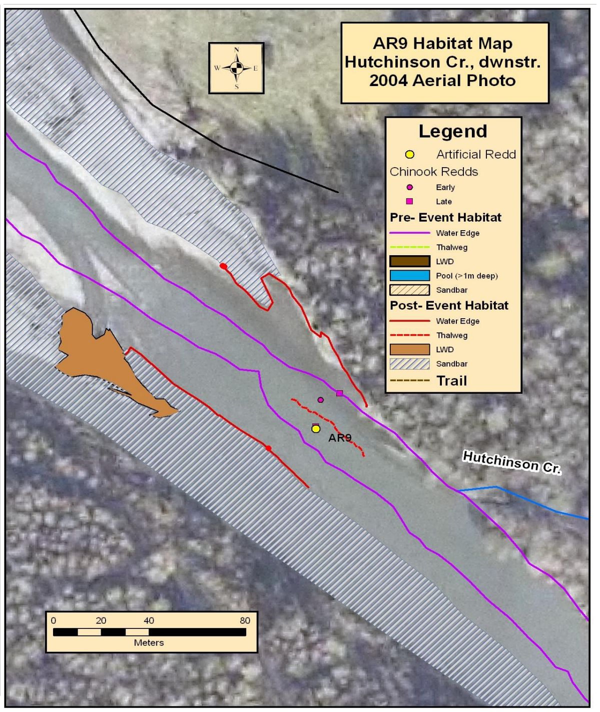


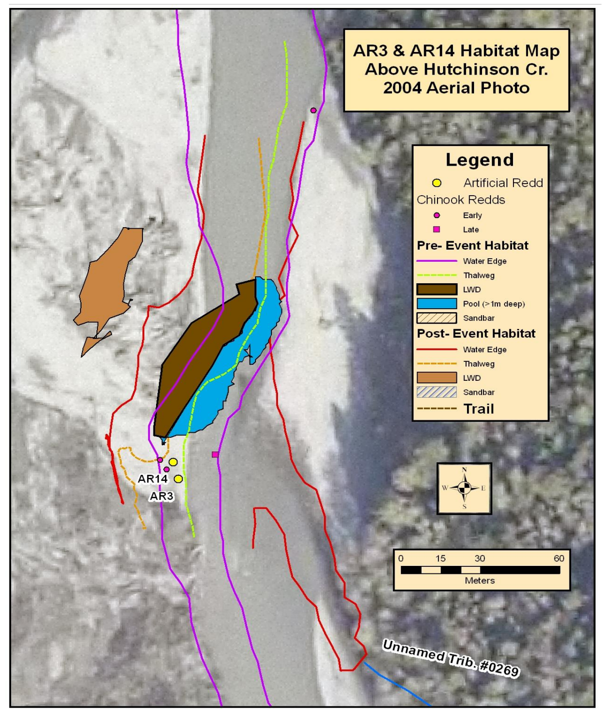


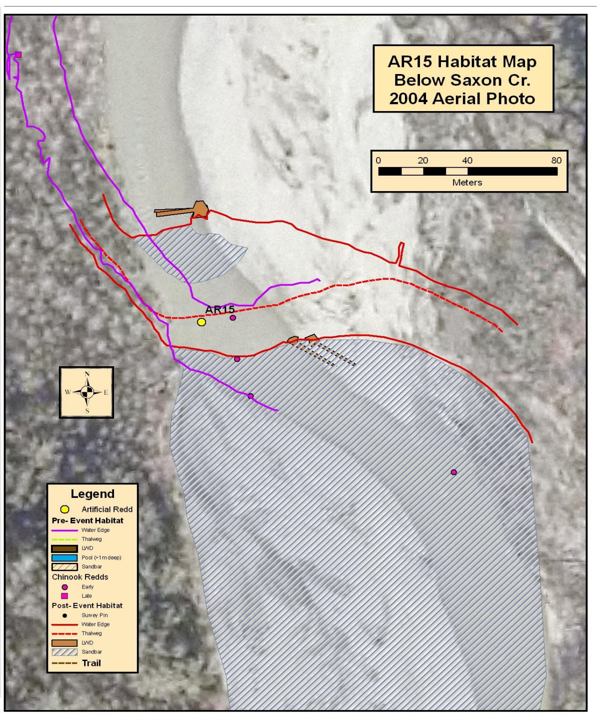


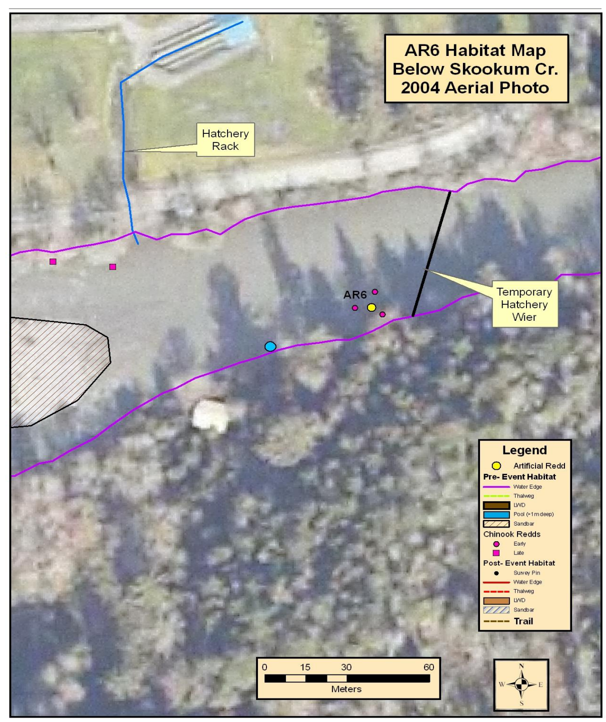


Appendix D2 Habitat Maps for Sites AR9, AR3/14, A15, and AR6.

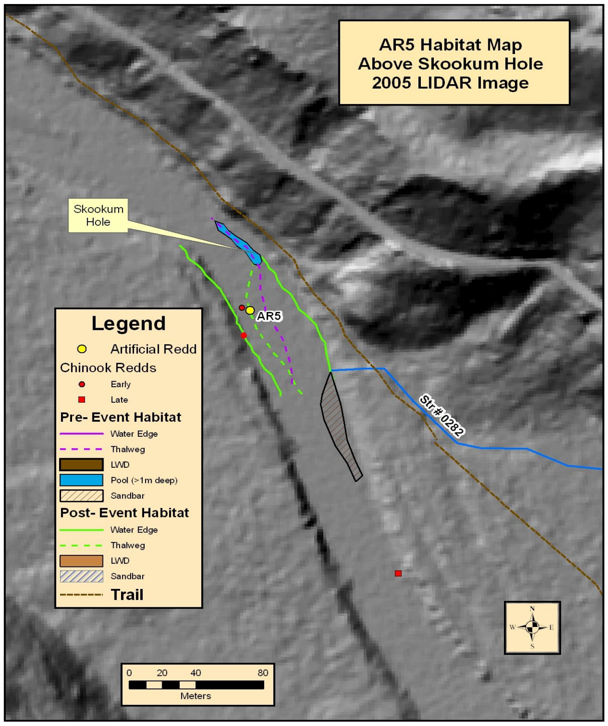


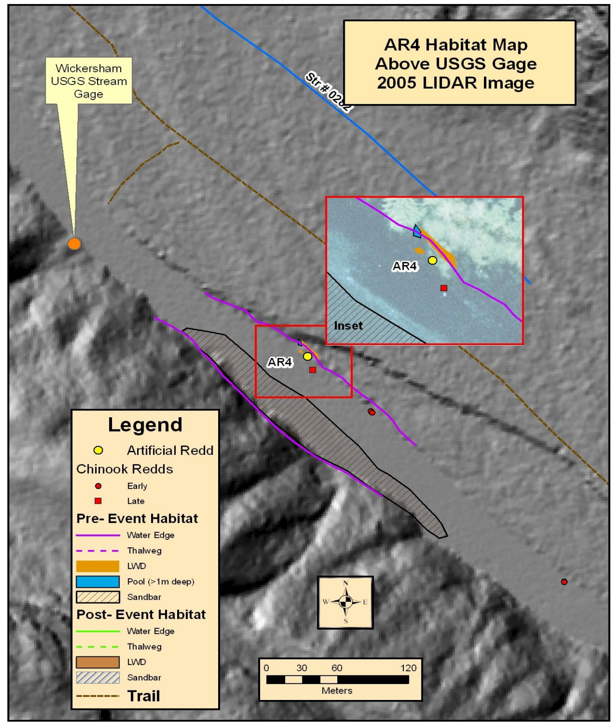


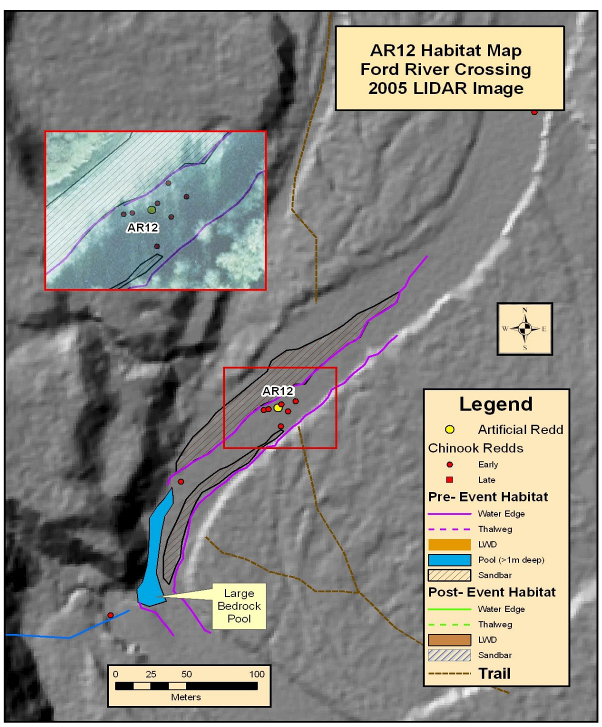


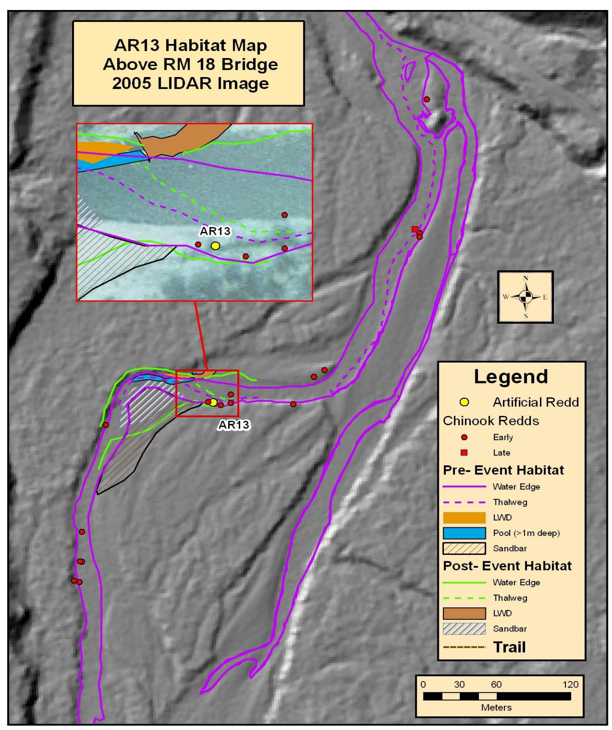


Appendix D3 Habitat Maps for Sites AR5, AR4, AR12, and AR13.

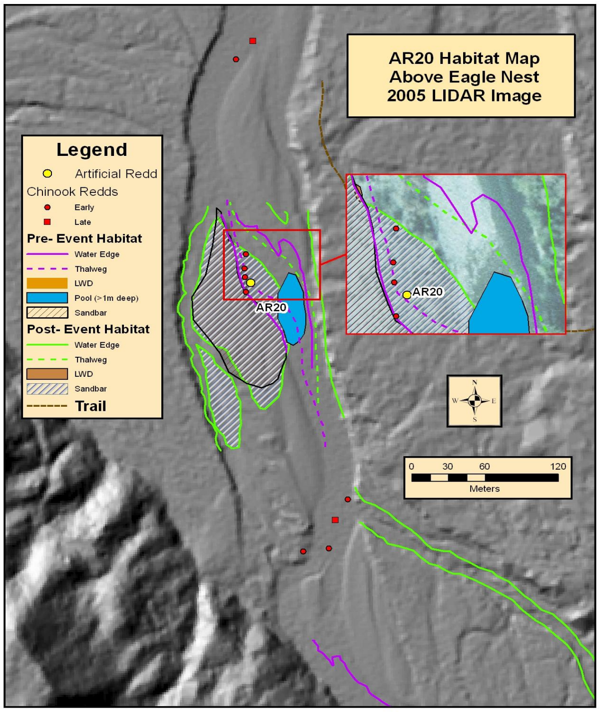


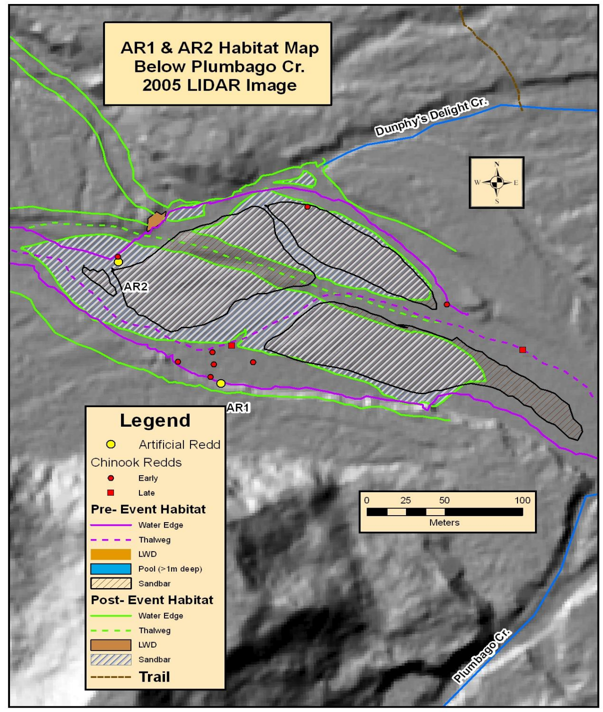


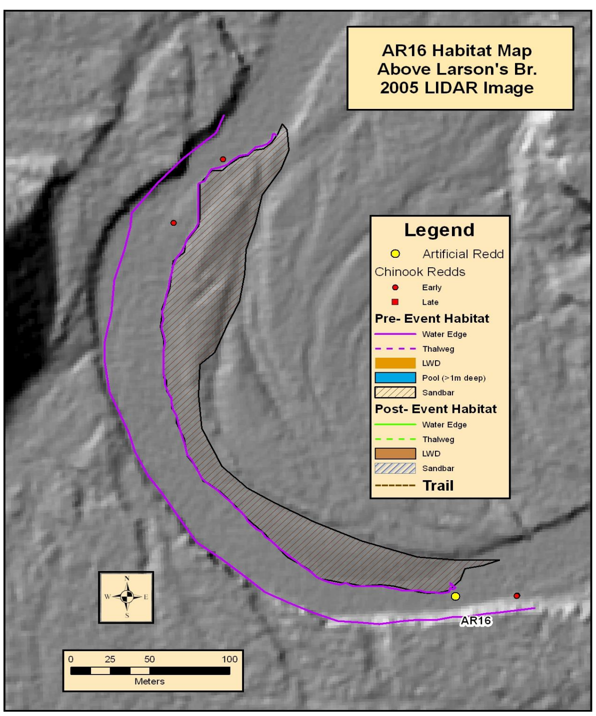


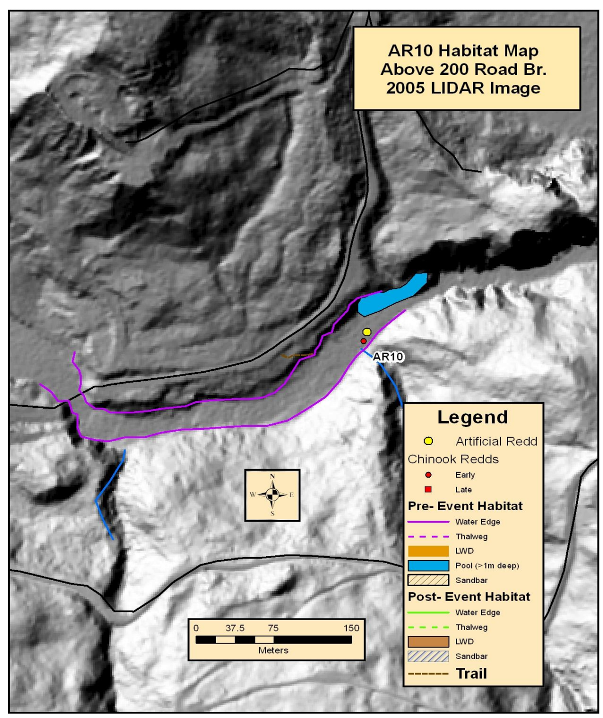


Appendix D4 Habitat Maps for Sites AR20, AR1/2, AR16, and AR10.

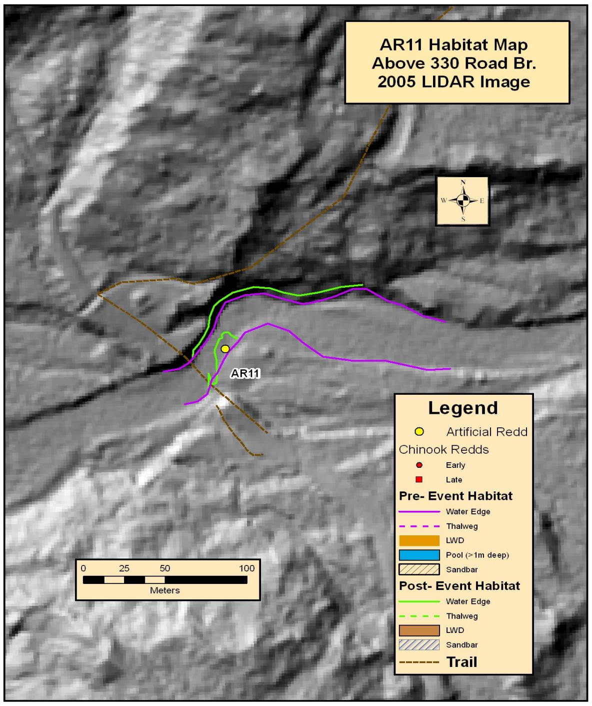


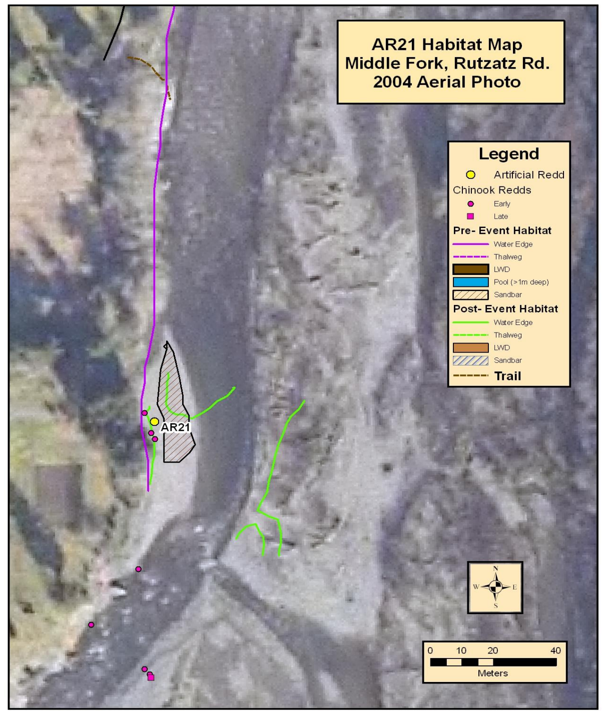






Appendix D5 Habitat Maps for Sites AR11 and AR21.





Appendix E. Sediment infiltration data for the South and Middle Fork Nooksack River in 2006 / 2007.

	Early Incubation		Post-Incubation		
Site:	**AR14**	**AR20**	**AR12**	**AR19**	**AR21**
Collected:	9/12/06	9/29/06	2/2/07	7/17/07	4/11/07
Stream:	S. Fork	S. Fork	S. Fork	S. Fork	M. Fork
WIRIA:	#'0246	#'0246	#'0246	#'0246	#0339
RM:	10.89	3.87	17.01	3.87	1.80

Sieve Size (mm)	Displaced Volume (ml)	Displaced Volume (ml)	Displaced Volume (ml)	Displacec Volume (ml)	Displaced Volume (ml)
75.0	0.0	0.0	0.0	175.0	0.0
26.5	1,414.0	1,235.0	1,656.5	1,582.0	1,280.0
9.50	1,605.0	910.0	1,311.0	890.0	262.0
6.70	421.0	255.0	195.0	292.0	75.0
3.35	1,319.0	523.0	475.0	357.0	145.0
2.00	395.0	193.0	435.0	300.0	102.0
1.70	93.0	88.0	88.5	71.0	29.0
0.850	401.0	212.5	579.5	602.0	133.5
0.425	418.0	114.0	475.0	949.0	171.5
0.125	102.0	21.0	208.5	285.0	223.5
<0.125	8.0	1.0	180.0	260.0	50.0
Sample Total=	6,176.0	3,552.5	5,604.0	5,763.0	2,471.5
Total<0.85=	528.0	136.0	863.5	1,494.0	445.0
Percent <0.85	8.5%	3.8%	**15.4%**	**25.9%**	18.0%
Rating=	Good	Good	Fair	Poor[1]	Poor

[1]Sample collected ~ 3 months after emergance period.

Appendix F. Summary of post-emergance artificial redd observations, 2007.

Summary of Post-emergance Observations At Artificial Redd Sites in 2007

Redd ID #	Location	River Mile	Post-emergance Site Observations	Presumed Redd Survival
AR8	Above Potter Br.	2.03	Evidence of vandalism	Unknown
AR19	Below Sygitowitz Cr.	3.87	Sediment sample has high percent fines	Poor - Fine Sediment
AR18	Above Standard Cr., dwnstr.	6.2	Site located & excavated - no frame found	Poor - Scour
AR17	Above Standard Cr., upnstr.	6.36	Site located & excavated - no frame found	Poor - Scour
AR7	Above RR Bridge	7.83	Site located & excavated - no frame found	Poor - Scour
AR9	Below Hutchinson Cr.	10.05	Site located & excavated - no frame found	Poor - Scour
AR3	Above Hutchinson Cr.	10.89	Site located & excavated - no frame found	Poor - Scour
AR14	Above Hutchinson Cr.	10.89	Site located & excavated - no frame found	Poor - Scour
AR15	Below Saxon Creek	11.48	Site too swift to visit	Unknown
AR6	Below Skookum Creek	14.17	Site located & excavated - no frame found	Poor - Scour
AR5	Skookum Hole	14.52	Site located & excavated - no frame found	Poor - Scour
AR4	Above Stream Gage	14.92	Site located & excavated - no frame found	Poor - Scour
AR12	Ford River Crossing	17.01	Sediment sample has moderate percent fines	Fair - Fine Sediment
AR13	Above RM 18 Bridge	18.31	Site located & excavated - no frame found	Poor - Scour
AR20	Above Eagle Nest	19.33	Site on exposed sandbar / fry found in substrate	Poor - Deposition
AR1	Below Plumbago Cr., LB	19.78	No frame at site	Poor - Scour
AR2	Below Plumbago Cr., RB	19.73	No frame at site	Poor - Scour
AR16	Above Larson's Bridge	21.86	Missing pins / poor GPS	Unknown
AR10	Above 200 Road Bridge	24.9	Missing pins / poor GPS	Unknown
AR11	Above 330 Road Bridge	29.94	Deposition 3 m +	Poor - Deposition
AR21	M. Fork, Rutzatz Rd.	1.8	Frame 2/3 exposed	Poor - Fines & Scour